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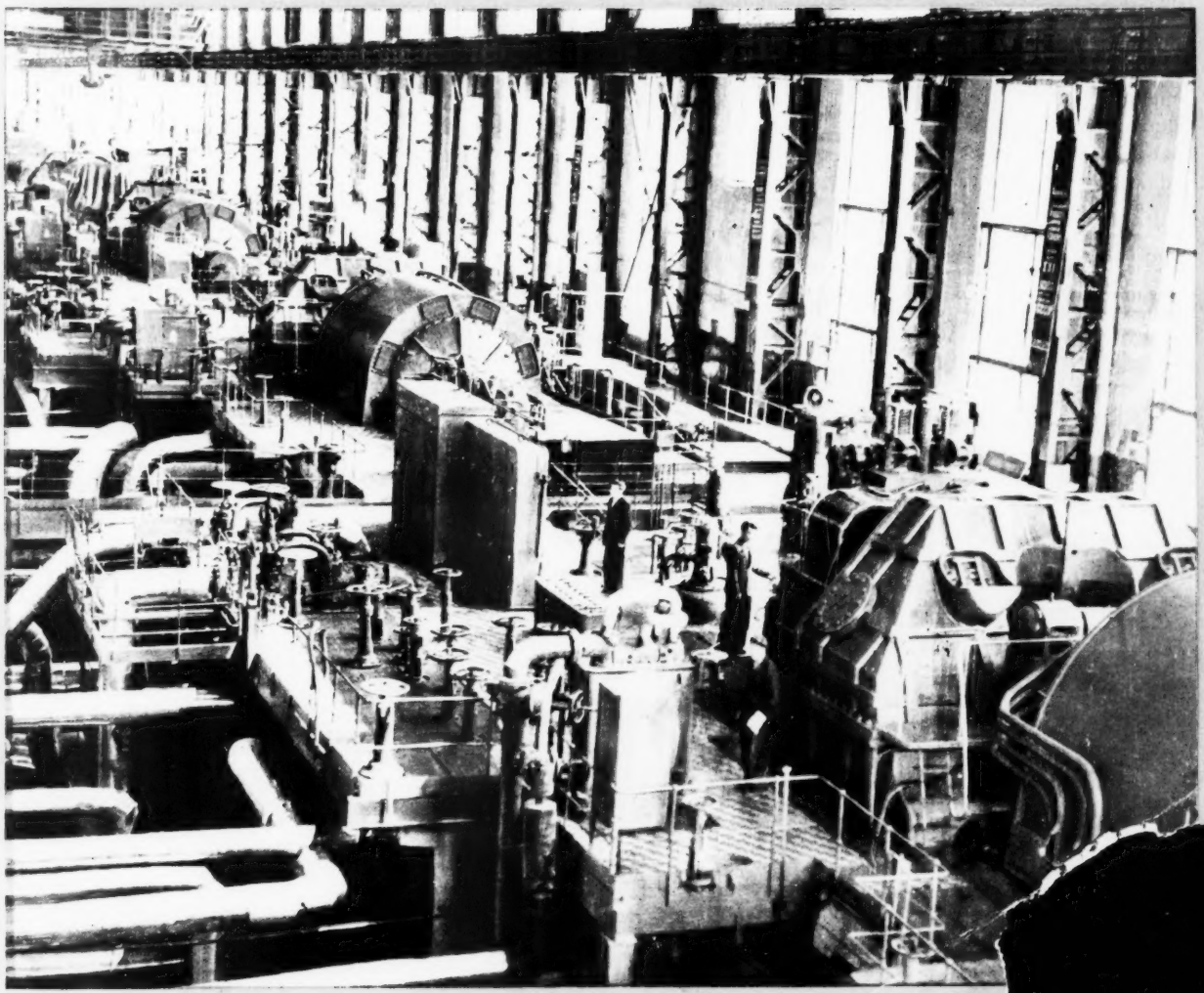

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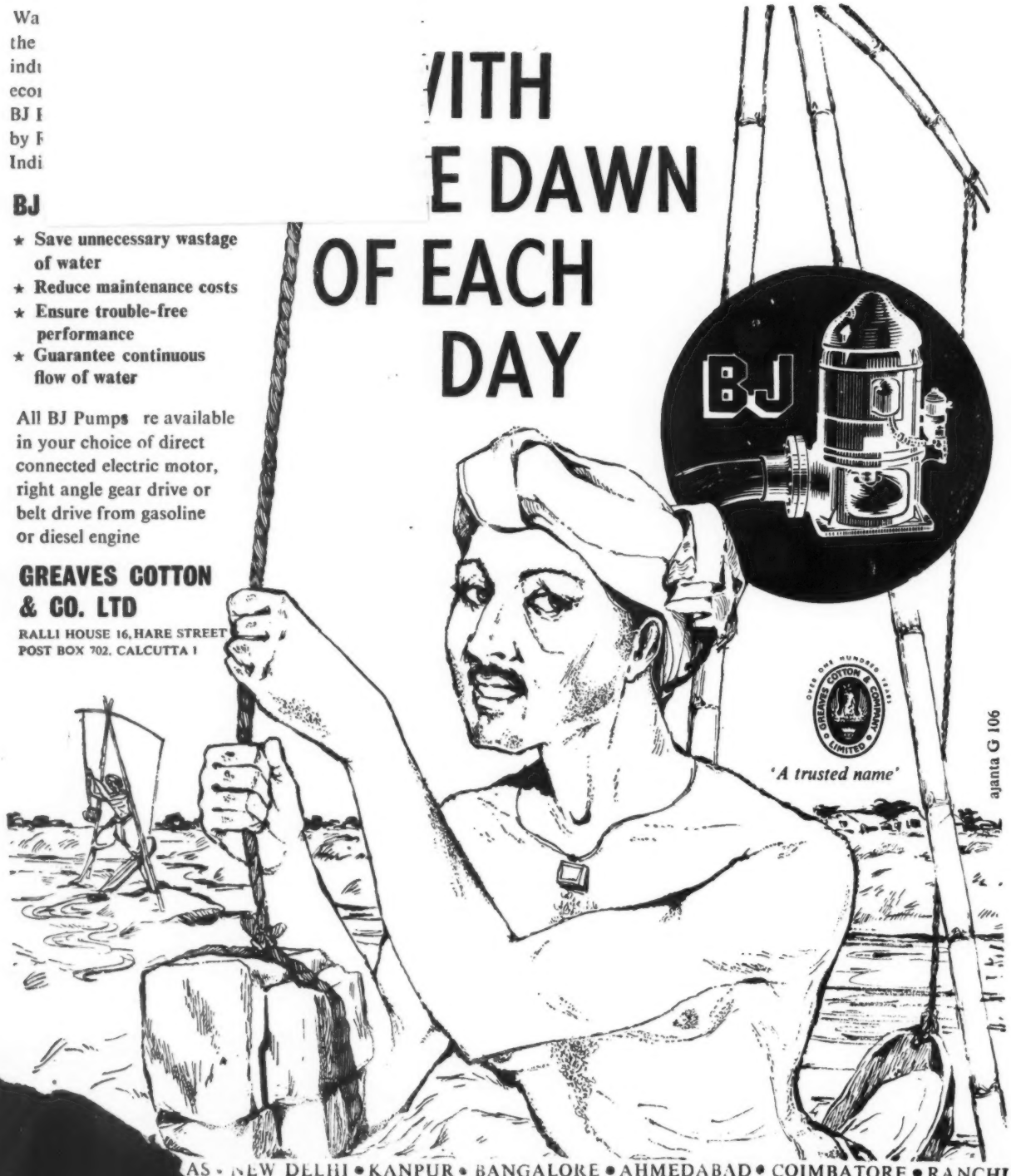

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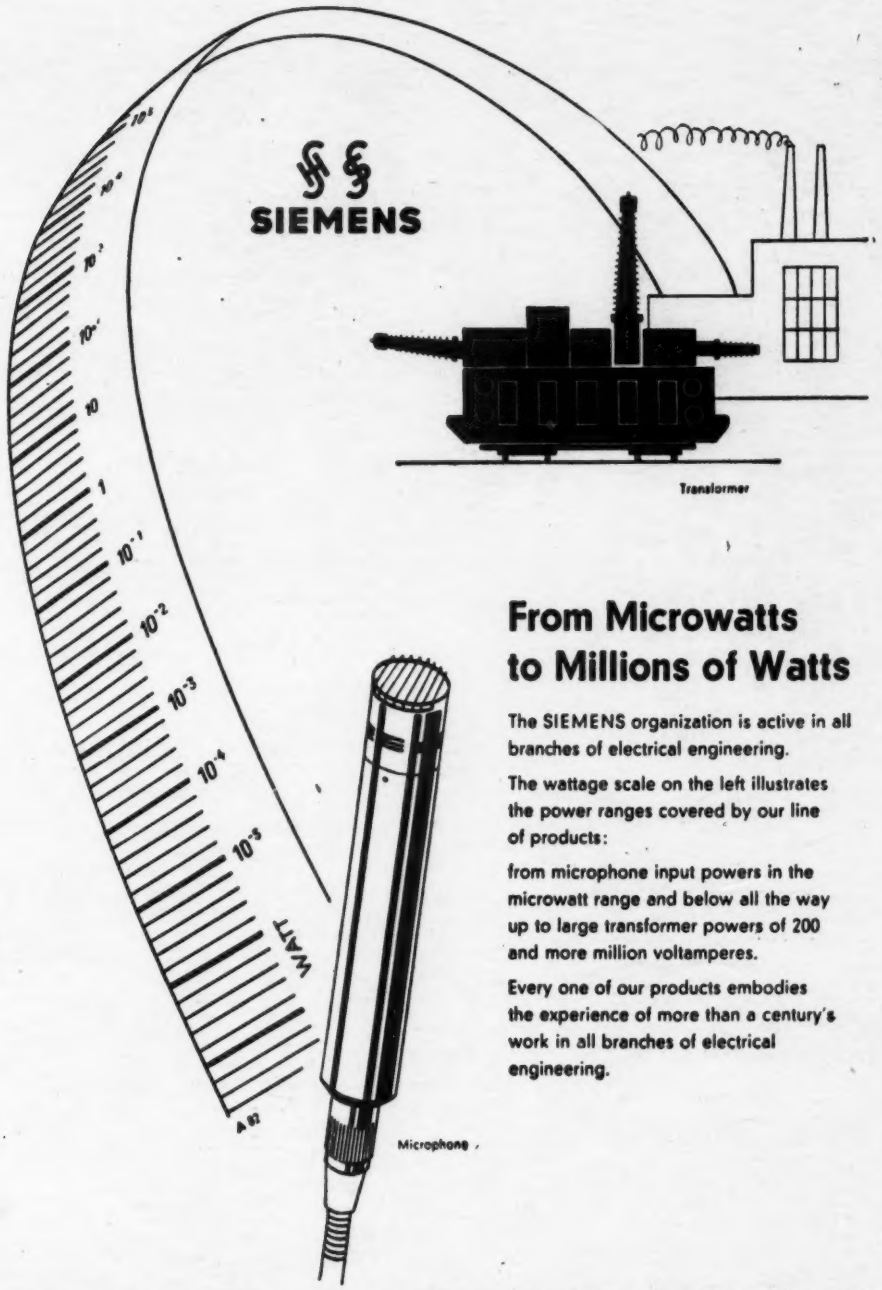

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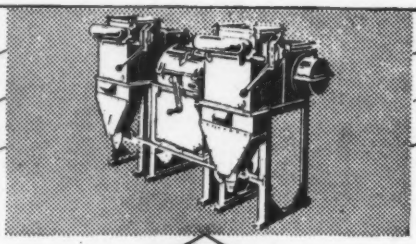

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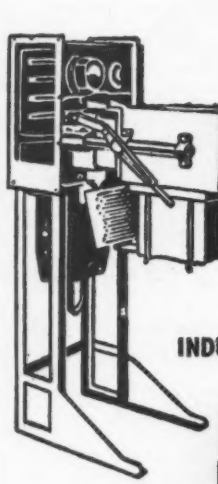
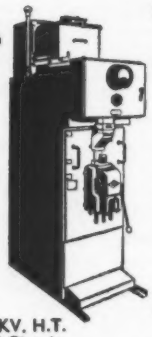
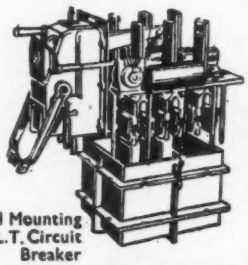


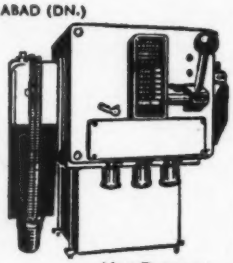
Horizontal L.T. Drawout Circuit Breaker



11 KV. H.T. Oil Circuit Breaker

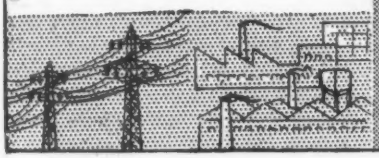


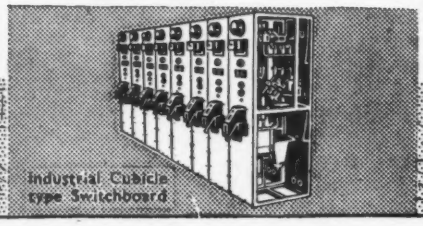
Panel Mounting L.T. Circuit Breaker



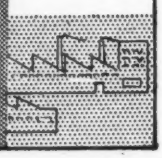
Non-Drawout L.T. Oil Circuit Breaker

IA-50





Industrial Cubicle type Switchboard



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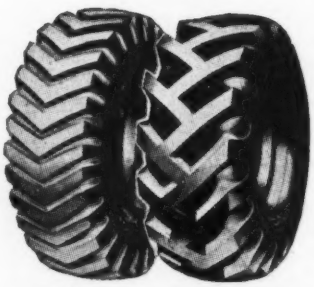

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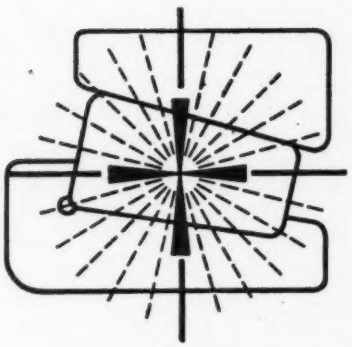

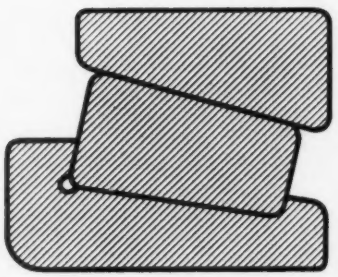

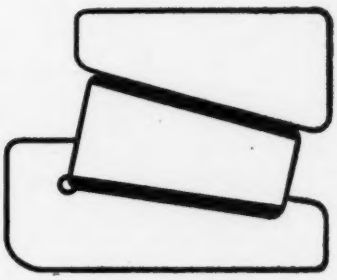

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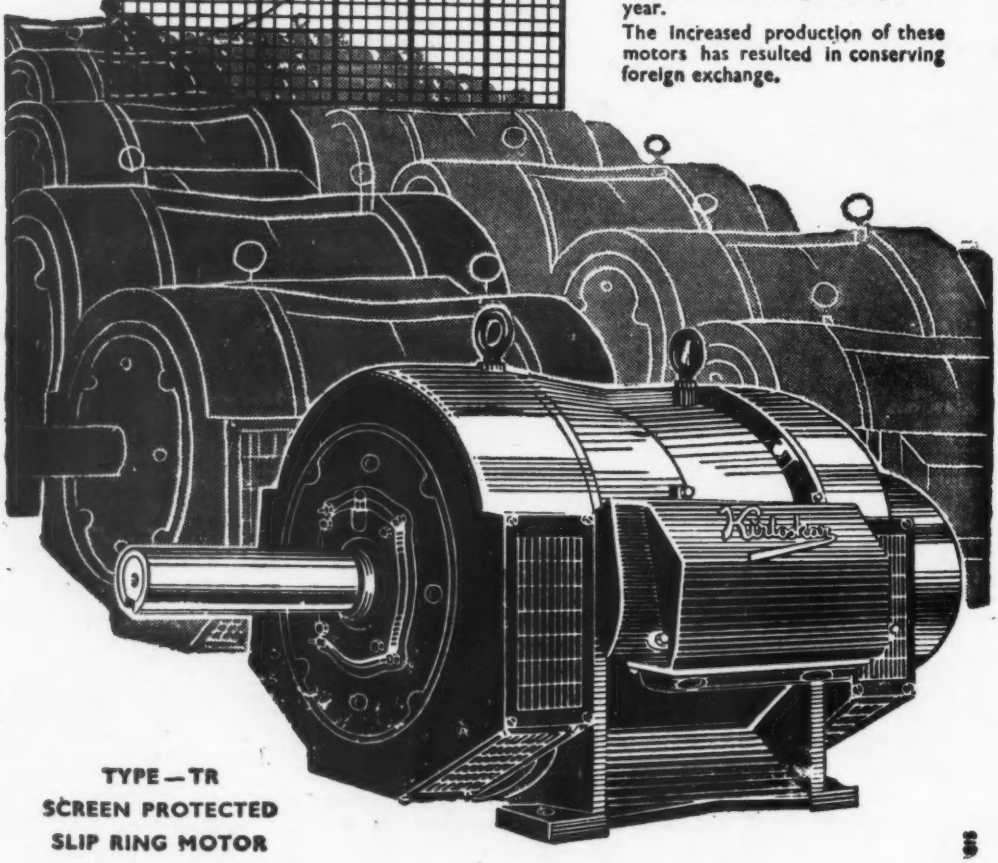

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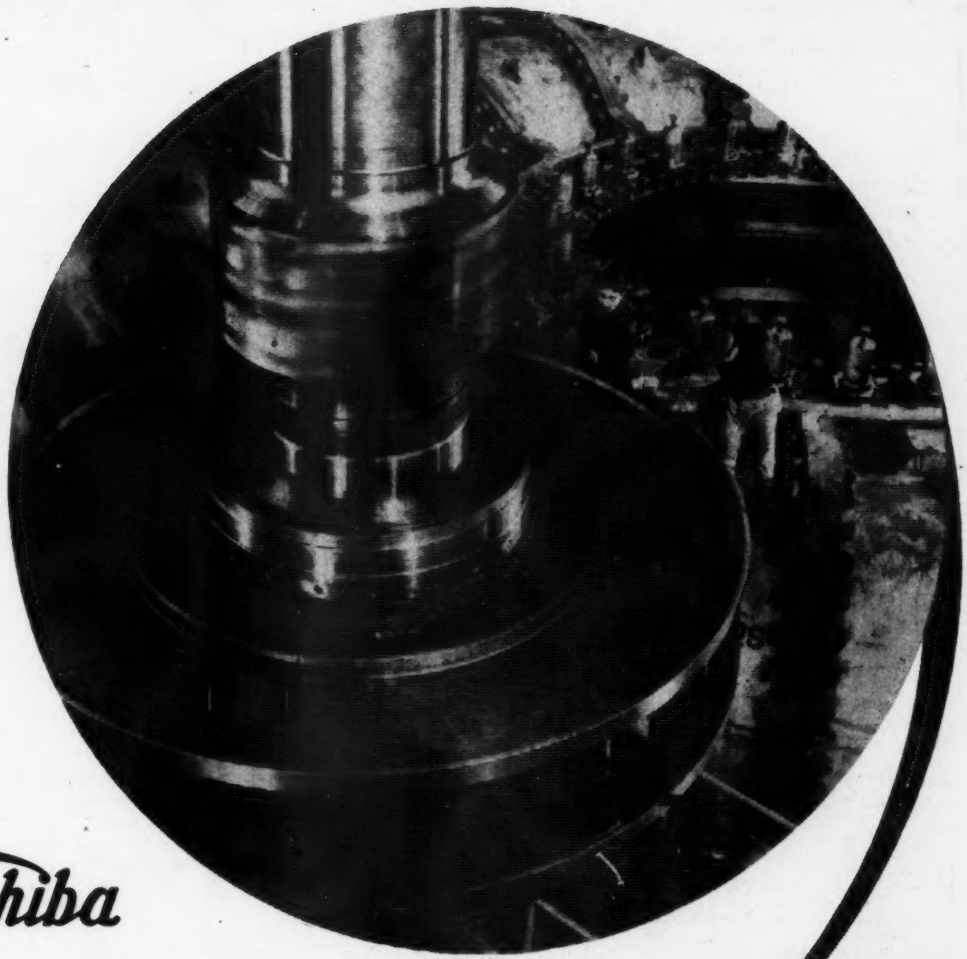

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The generator on the right is the second largest of its type in the world. It was built by Toshiba for installation at Japan's new development project, the Okutadami Power Station. It generates 133,000 kVA and was designed big to do a big job. For information about this or any other type of equipment necessary for generating or transmitting electric power, be sure to consult Toshiba.

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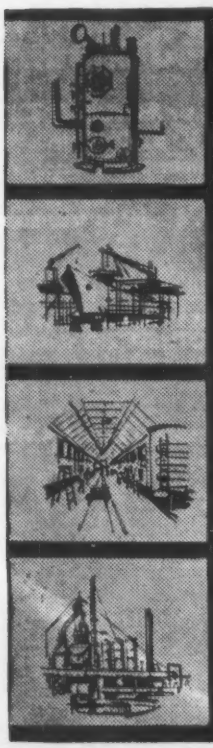

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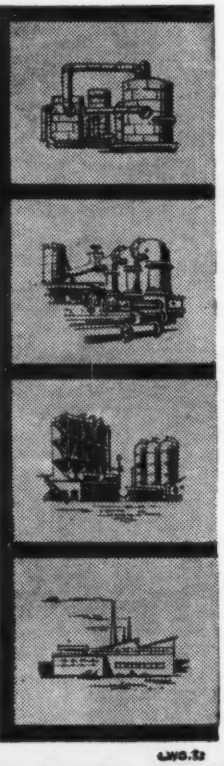

LWD.52

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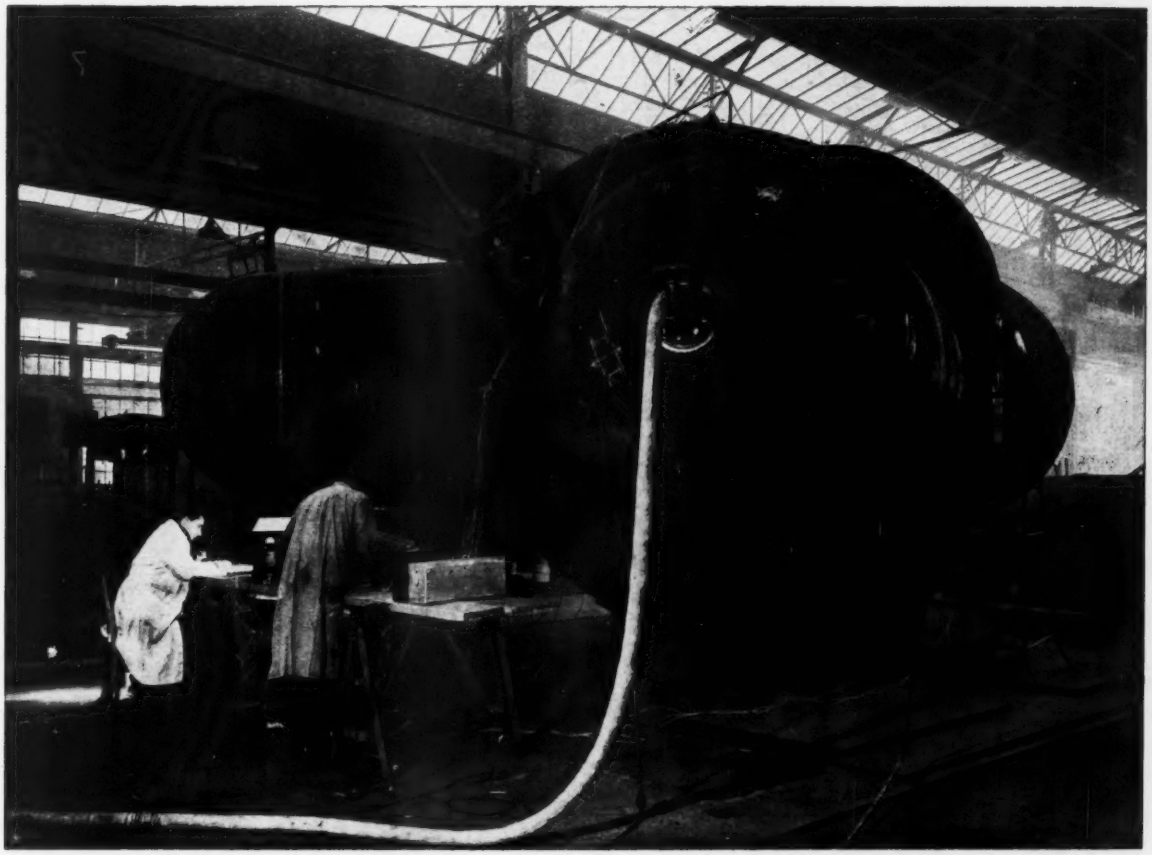

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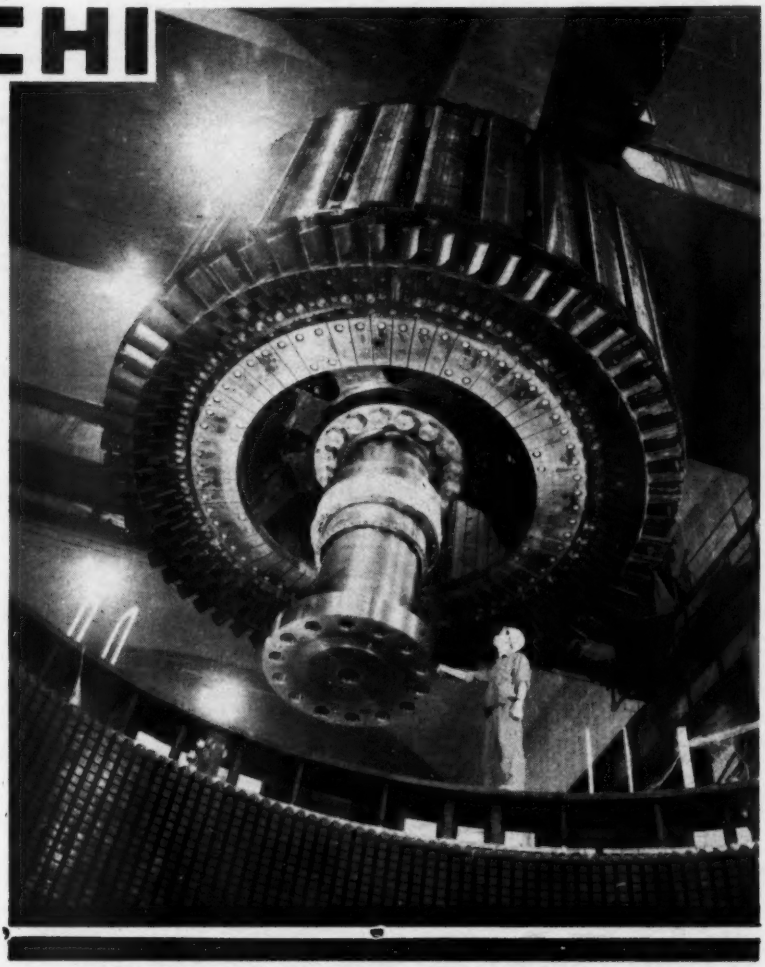

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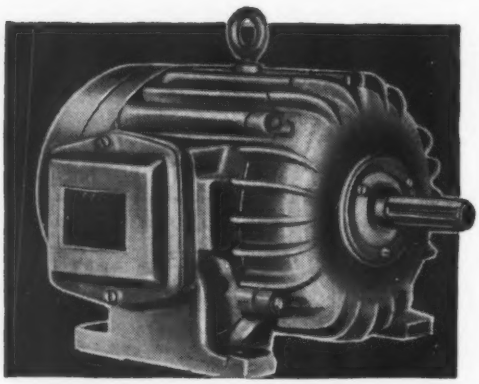

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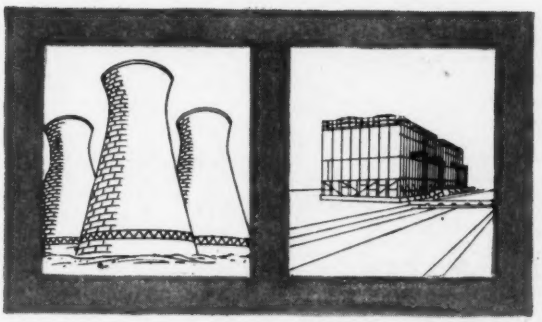

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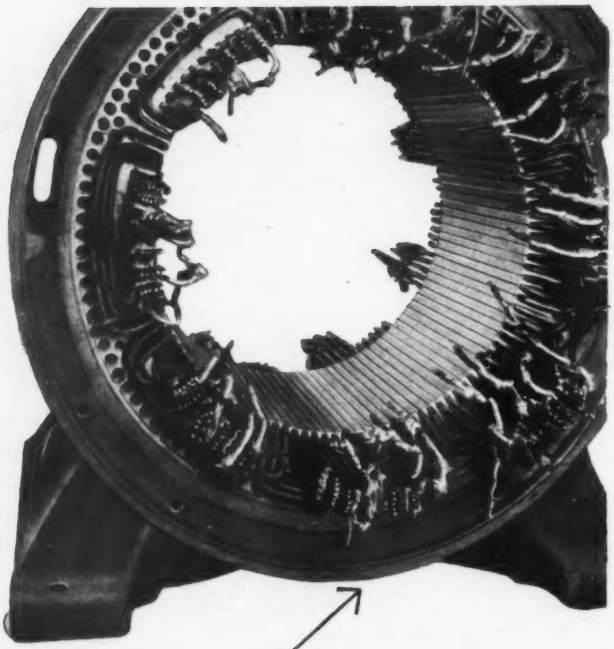

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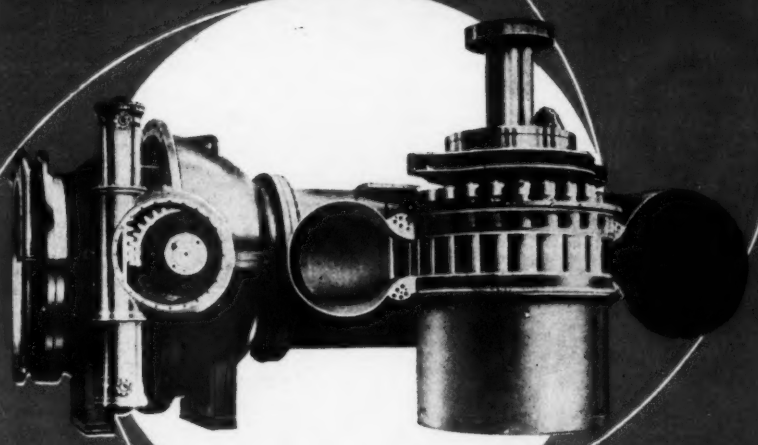

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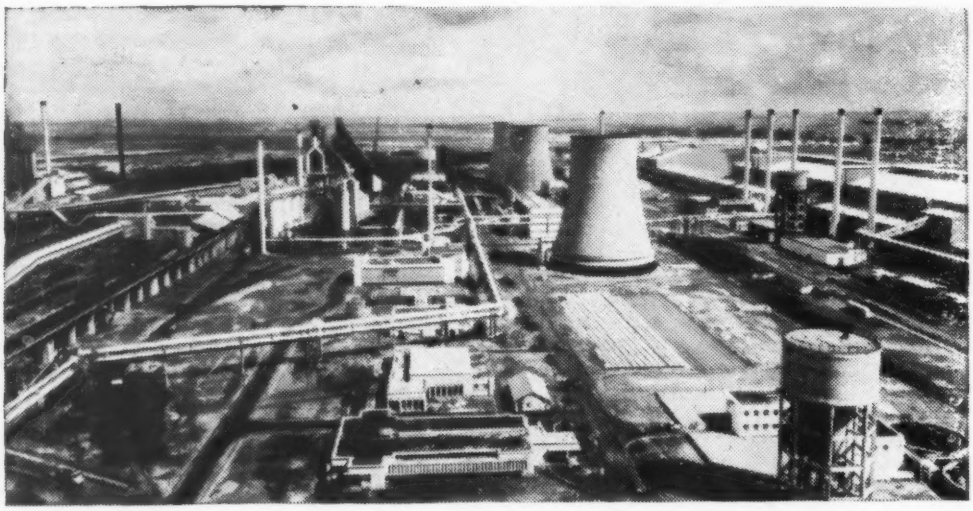

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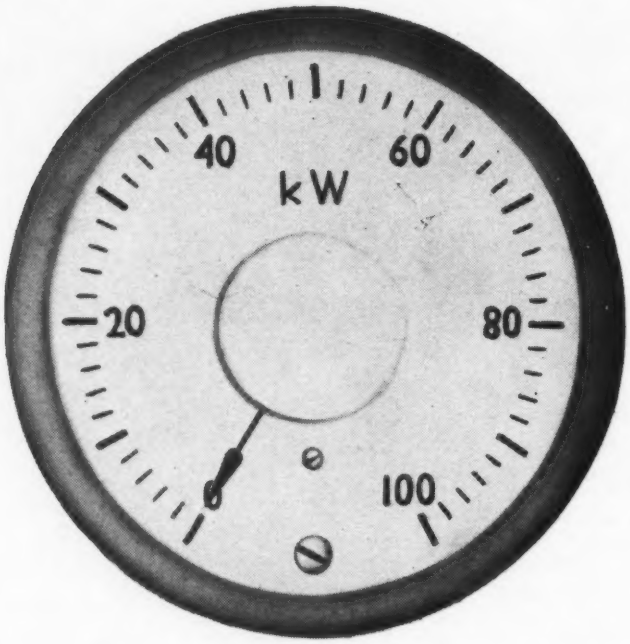

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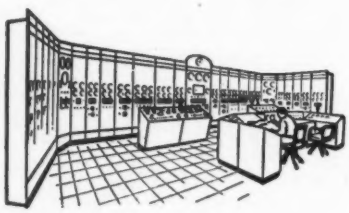

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Flood Control in India : A Retrospect and Prospects

By R. D. DHIR and R. K. JAIN

Floods are a natural phenomenon with which all people who live in the vicinity of rivers are familiar. They are common to nearly all parts of the world. Reliable historic records of floods are available for centuries past for some of the principal rivers in Europe. The historic accounts of the Mississippi and other rivers in U.S.A. date back to De Soto in 1543.

The rivers in floods perform the vital function of carrying away the excess precipitation and also the products of erosion to the sea. The fertility of the rich silt deposited by the river waters in their valleys promote large settlements. The valleys are thus not only intensively cultivated but are also occupied by homes, factories, railways, highways etc., with the result that the floods cause much greater damage. The demand of the river for its flood plain and that of the man for land to be occupied are opposed to each other. With the increasing population, more and more of the flood plain is occupied, and greater and greater risks of losses from floods have to be faced.

Floods are caused by concentrated rainfall. There are, at present, no known methods of controlling rainfall. High flood discharges are, therefore, inevitable. All that is attempted by flood control measures is to minimise the flood damage as much as possible. Even in making this attempt, it has to be clearly understood that complete immunity from flood damage is not possible, for even if it is technically practicable, it is financially not feasible.

METHODS OF FLOOD CONTROL

The methods of reducing flood losses fall into two main categories. The first category includes methods for physically controlling floods, reducing flood heights, lessening areas of overflow and checking bank erosion. They comprise works such as embankments, reservoirs, detention basins, channel improvements, river training, diversion of a part of the flood discharge into other natural or artificial channels, watershed improvements. The methods in the second category do not attempt to reduce flood flows or flood levels but aim at reducing the resulting flood losses. They are flood plain zoning, evacuation of property located in flood affected areas on receipt of flood warning, and raising village habitations.

Every method of flood control has its advantages and its limitations. The final selection of the method to be adopted in a particular case depends not only on its technical merits but also—and probably more—on its economic justification and other considerations such as availability of funds, labour and material.

Amongst all the methods mentioned above, embankments are the oldest form of protection against floods. Their chief advantages are the relatively lower cost, the availability of construction material in the immediate vicinity, and the ease with which the entire construction can be carried out by unskilled labour locally available in regions where the embankments are to be constructed. They have their limitations too, the chief being that they are liable to breach by either overtopping, erosion or seepage of water unless adequately maintained. Embankments deprive the land of the beneficial effect of fertilising silt by cutting off the river spills. This exclusion of silt from the flood plains also retards the building up of lands and hastening the extension of delta into the sea. Another important limitation is that the available valley storage gets decreased, resulting in higher flood peaks downstream.

Divergent opinions have been held about the overall advisability of putting up embankments as a measure of flood control. Although their limitations are well recognised, yet their advantages generally tend in practice to tilt the balance of decision in their favour.

Reservoirs, are no doubt, effective in reducing flood peaks in the lower reaches of the streams but their effect diminishes rapidly as one goes downstream. They require considerable time for extensive surveys and collection of data in the valley for location of suitable dam sites. In a number cases, it is not possible to find an economically feasible site for the construction of a dam. The cost of creating an artificial reservoir purely for flood control, is generally not justified and the scheme has to be made multipurpose by including some uses of the water stored, which may not be always possible. After construction, a dam requires very careful operation by skilled and trained personnel. On the

whole, wherever it is possible to create a reservoir and make use of the water stored, it is no doubt one of the best methods of flood control.

As distinct from reservoirs, detention basins are natural smamps and lakes, improved and regulated by man to serve his needs of flood moderation. During high floods, water spills and flows into these depressions, later to flow back into the river. This process brings about reduction in flood peaks in the river downstream. The area of the detention basins has to be very large in the case of big rivers to bring about any appreciable flood moderation and such detention basin may not actually exist. However, flood moderation by means of detention basins, where feasible, is one of the cheapest forms of flood control, the control works being of low head and relatively inexpensive.

In the case of channel improvement works such as straightning of the river channel, cutoffs, etc. marked reduction in flood stages on a stream at a specific point can be achieved. But an ultimate knowledge of the river and its behaviour supplemented by model tests is generally necessary before their execution. Channel improvement works are costly and are suitable, when besides flood control, it is intended also to stabilise the river channel to a planned alignment for navigation etc.

The method of diversion of part of the flood flows into another river enables considerable reduction in flood damage by utilising the capacity of the other river. But this method can be adopted only when flood peaks of the two rivers do not synchronise, and when the capacity of the river into which water is to be diverted is enough to accommodate surplus water of the other river. The suitability and success of this method depend mainly upon the geography of the country and the hydrology of the channels.

Water-shed improvement is an important method of reducing silt-load which causes damage by erosion and silting of beds thereby raising the flood heights and changing the river course etc. It helps in the reduction of flood peak from small watersheds with moderate rainfall. However, its effect is insignificant in case of high floods or big watershed, although it serves even in such cases, the important purpose of preventing excessive loss of soil.

A good deal of annual loss could be avoided by flood plain zoning whereby, areas along a river are demarcated and people are prevented from creating valuable assets in the waterways necessary for passing high floods in the river. This may involve some administrative difficulties as it is difficult to demarcate the flood zone with legal provision. The success of this method depends on the co-operation forthcoming from the people.

A great deal of loss and suffering can be avoided by having a system of flood forecasting and flood warning as it gives some notice for men and valuable property to be removed to safer places This system requires a comprehensive study of the river basin to evolve a technique appropriate to the conditions obtained on the river. Such a system is very useful on large rivers where a fairly large time lag exists between the flood producing--rainfall and the occurrence of flood peak at the points downstream where flood warning is required.

The method of raising habitations or important places above flood heights is resorted to where it is otherwise undesirable or uneconomical to prevent the annual inundation of areas during the flood season and where the property is subjected only to inundation and not to erosion.

It may be mentioned that a complete answer to the different kinds of flood problems cannot be found in any single measure. Each case has to be considered on its merits and a measure or a judicious combination of several measures has to be adopted.

FLOOD CONTROL IN INDIA: A RETROSPECT

The problem of flood control is not new to India. As in other countries of the world, almost every river in India swells up, some time or the other, spills over its banks and causes considerable damage. The earliest efforts in the field of flood control took the shape of embankments put up by private individuals for the protection of specific cultivated areas or villages. As the individual efforts proved inadequate and sometimes mutually opposed to one another, the State Governments took up the work of constructing well-co-ordinated and planned embankments on problem rivers during the past century. The notable rivers having long lengths of such embankments are the Gandak, the Damodar, the Mahanadi, the Godavari, the Krishna and the Kaveri.

No reservoirs were constructed in the past for purposes of flood control. A large number of small tanks and some reservoirs, however, were constructed in south India for the purposes of irrigation and drinking water supply. These tanks though individually small, collectively afford considerable moderation in flood peaks during the early part of monsoons. In North India, on the other hand, big river diversion works were constructed. The efforts of those responsible for development of irrigation works in India were in the earlier times, directed naturally to such resources as were easy to exploit. In North India, most of the rivers are perennial, whereas in South India the rivers, though swollen during monsoons, have little flow during the dry period. Therefore, while river diversion works are easy and economical to construct in North India, irrigation in South India is possible only by constructing tanks or storage works to ensure unfailing and regular supplies. During the last two decades many storage projects, multi-purpose in conception, have been taken up in India. In the North, storages have become necessary on rivers on which the available perennial supplies have been fully utilised by means of diversion works. Most of these storage

projects are for irrigation and/or power with flood moderation as an incidental benefit. The main projects with the primary object of flood control are the Hirakud Dam on the Mahanadi taken up in 1948 and the dams in Damodar Valley taken up in 1950.

After the Hirakud and the Damodar Valley Projects, flood control appears to have lost its importance in India till the year 1954 when there were disastrous floods in the country. It was then realised that effective flood control measures required a national effort and direction. A comprehensive National Programme for flood control was, therefore, launched in year 1954 and a separate financial allocation made for the purpose. It was, however, found that no remedial works of a reliable character could be planned and designed on account of lack of hydrological and other data. It was, therefore, decided that the work of collection of basic data and carrying out the necessary surveys and investigations should be accorded the highest priority. As the flood damage was very heavy and recurrent in some parts of the country, and the remedial measures could not wait for the time to be taken in the collection of data etc., it was decided to taken up emergent works in such areas immediately. The National Programme was, therefore, divided into three phases. The first or the immediate phase extended over the first two years and was to be devoted to intensive surveys, investigations, collection of essential hydrological and other data and execution of emergent works such as protection of important towns, some embankments, raising of villages etc. The actual progress achieved on the aerial photography and spot levelling during these two years was about 43,000 and 16,000 sq. miles respectively. 1,000 miles of embankments were constructed and 1,400 villages were raised. This afforded protection to an area of about 30 lakhs acres.

The second or the short-term phase lasting for about 4 to 5 years, envisaged flood control measures such as channel diversions, construction of more embankments, protection of more towns and raising of more villages, the works being planned and designed on the basis of the data as it got collected. The need was to protect people, crops and public utilities in the flood affected areas by choosing the kind of works which, while achieving the object could be carried out expeditiously. As embankments could be constructed quickly and at a relatively lower cost, stress was laid on this method of flood control.

About 2,800 miles of embankments have so far been completed in various States thus affording protection to about 6 million acres. Three channel diversions have been undertaken. 46 towns have been protected from river erosion and/or flooding and 4,200 villages, mostly situated on the river side of the embankments, have been raised. On the survey and investigation side, the progress achieved has been 49,000 sq. miles of aerial photography, 40,000 sq. miles of spot levelling and 25,000 miles of levelling for longitudinal and cross sections.

A step towards soil conservation was also deemed necessary as the flood problem was aggravated by deforestation in upper catchment areas and consequent soil erosion, silting of river beds, and/or change in their courses. Some soil conservation works have been taken up in the worst affected areas. It is found even on the basis of the limited experience gained that this method, to be effective, takes a long time and requires a lot of expenditure.

Action has been taken in some States to demarcate on survey maps the areas liable to be flooded so that the people concerned may be cautioned against erection of permanent structures and cultivation of lands in the flood season within the flood zones. Flood warning systems to signal high flood gauges to important places lower down the rivers, have been set up in most of the States, where floods occur frequently. The State Governments are utilising the P & T telegraph/wireless and the Police wireless stations for sending flood warnings. A flood forecasting unit to predict high flood levels in the River Yamuna at Delhi has been established in the Central Water and Power Commission.

The third or the long-term phase envisaged flood control works such as storage reservoirs and detention basins. It also envisaged additional embankments, channel diversions and village raising on the basis of experience gained during the course of five or six years. This phase which would begin roughly with the beginning of the Third Plan period would represent the future outlook of flood control in India.

PROSPECTS

During the last six years, much has been done in India towards mitigating flood damage but much more, it has to be realised, remains yet to be done. It has been estimated that by the programme of flood control works carried out since 1954, the extent of likely damage has been reduced by about one-fourth as compared to the average annual damage during the last decade and by about one-tenth as compared to the maximum in any one year during that period.

The experience so far gained in India has bought out forcibly the importance of an integrated basin-wise approach to the problem of flood control. A step taken at one place to solve a local problem, may have serious repercussions downstream or even upstream. Therefore, flood control on a river has to be planned by treating it as a unit even though it may be passing through more than one state. Each State in India has to prepare an outline Plan for that part of each river which falls within its boundaries and the Centre has to co-ordinate these

outline Plans for each river so as to get an integrated Master Plan for the entire river. One river—One Plan is the basic idea.

The High Level Committee on Floods, appointed by the Government of India in 1957, have recommended the lines on which a satisfactory Master Plan of flood control on a river should be prepared. They have recommended that such a plan should contain long-term measures for flood control including a study of the different possibilities, their combinations and their inter-se priorities by taking into consideration the following important factors:—

(*i*) Hydrological characteristics of the river and its tributaries;

(*ii*) Economic factors having a bearing on the flood problem like population intensity, industries etc;

(*iii*) Past history of floods, including duration, depth, frequency of past floods and an analysis of damage;

(*iv*) Review of measures undertaken in the past, including the reports of Expert Committees, if any;

(*iv*) Study of existing, under-construction and future water development projects in the river basin and

(*iv*) Adequacy of Hydrological and other data.

Probably the most important recommendation of the High Level Committee in connection with the formulation of Master Plans of flood control is the study of the existing, under-construction and future water development projects in the river basin. While flood control generally assures protection of what we have, it does not in itself mean a positive utilisation of water for development like irrigation or hydropower. Therefore, flood control schemes have to be integrated with other water development schemes and not dealt with in isolation. This concept is simple enough and has already been recognised in all countries including India. But there is one aspect which deserves special mention, particularly under the conditions obtaining in India at present. Although integration of flood control with irrigation and hydropower development is of equal importance, yet there are at present greater possibilities of its integration with the development hydropower. There is tremendous power potential in the Himalayan belt and since the areas most affected by floods lie in the sub-Himalayan region, there are immense possibilities of making the power development schemes in this belt multipurpose by including the aspect of flood control in them.

FLOOD CONTROL IN INDIA VIS-A-VIS OTHER COUNTRIES

In advanced countries like China and America which experience recurring floods, several methods of flood control are in vogue. In China, embankments have been in use for thousands of years. Fifty-six per cent of the total arable area in that country is protected by embankments. They have started recently to supplement embankments by detention basins, storage reservoirs and channel diversions.

In America, the earlier flood control works took the form of levee construction. The first system of levees was completed on the Mississippi in 1727. In 1927, the Mississippi experienced disastrous floods and many storage reservoirs, detention basins, channel diversions and new embankments have since been planned and constructed. Large scale research work in soil conservation measures in that country has indicated that such measures would be effective in reducing the flood peak only in small water-sheds with moderate rainfall and that their effect would rapidly decrease with the increase in the area of the watershed and/or in the rainfall intensity. Comprehensive flood forecasting and flood warning systems have also been evolved in the United States on problem rivers such as the Lower Mississippi and the Missouri to give timely warning to the people lower down the rivers.

In India, as in China and several other countries, embankments have been in use for thousands of years for protection against floods. The use of multipurpose reservoirs with flood control as one of its benefits, is comparatively a recent development. Many schemes for protection of towns and raising of villages have of late been taken up. A beginning has been made towards soil conservation by taking up work in the worst affected areas in the first instance. Steps have also been taken to set up flood warning systems in most of the States, where floods occur frequently. A comprehensive approach to the problem of flood control is now being aimed at by the preparation of a Master Plan for each river.

It would be clear from the above that the experience gained and the approach being made in India towards flood control compares favourably with the experience and approach in other large countries like America or China and, therefore, we should go ahead confidently with our flood control programme, which aims at a target of reducing 50 per cent of the damage at present caused by the floods.

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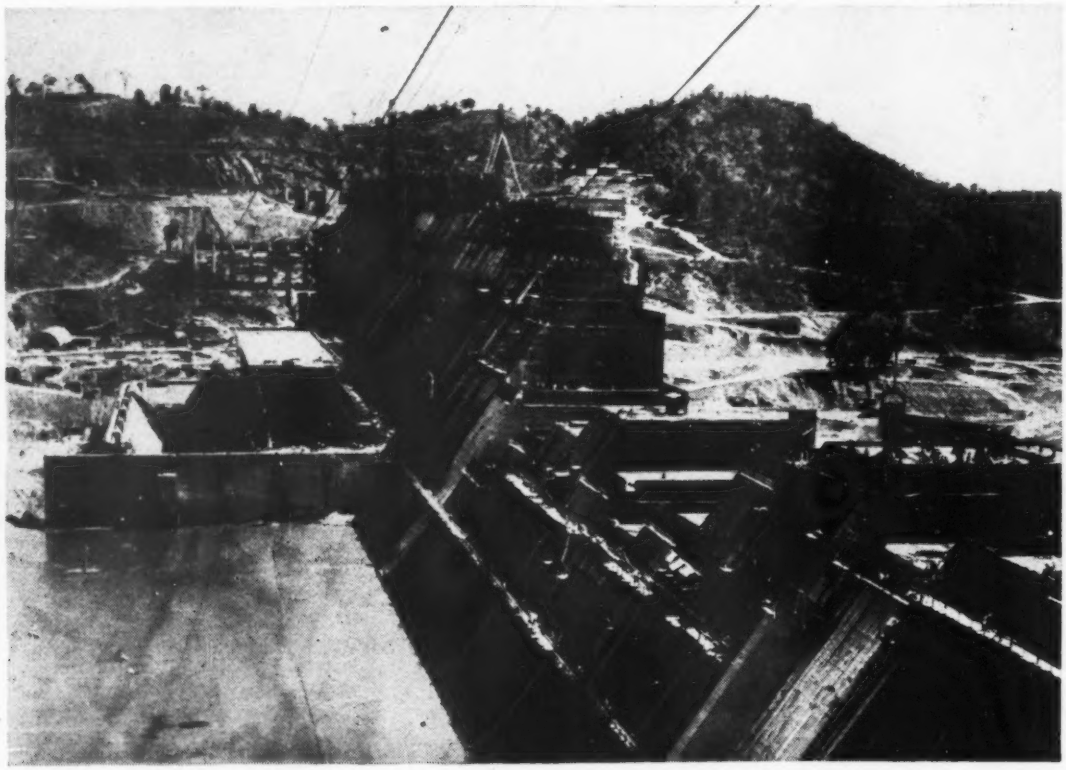

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Mettur Tunnel Hydro-Electric Scheme

V. P. APPADURAI

The Mettur tunnel hydro electric scheme is the seventh hydro electric project undertaken by the Department. On completion of the first stage the scheme will add 100,000 kW installed capacity to the Madras Grid.

The scheme is to utilise the irrigation discharges at Mettur Dam in Salem District to develop power for about 7 months in the year. The Mettur Dam and reservoir are located at a distance of about 30 miles north west of Salem Town in Salem District (between longitude 77°30 mts. East and 78° East and latitude 11°30 mts. north and 12° north). The dam built across the Cauvery river during 1925 to 1934, is 170 ft. high above bed of the river and more than a mile long. The reservoir has a gross capacity of 93,500 M.Cft. at full reservoir level and is mainly intended for irrigation purposes.

There are two sets of irrigation sluices in the Dam viz. the high level sluices and the low level sluices. The high level sluices have 8 vents, each 10'6" wide and 16 ft. high. The low level sluices have 5 vents, each 7 ft. wide and 14 ft. high. Four hydro electric pipes each 8½ ft. dia (sill level—plus 640) and of capacity 1250 cusecs each are used for power purposes under varying heads of 60 ft. to 160 ft. These pipes feed four generators each of 10,000 kW capacity on the unit system. At present the average irrigation discharge is about five times the average power discharge through these hydro electric pipes. The irrigation requirements over 4000 cusecs are therefore allowed to flow through, the high and low level sluices without generating any power. The present scheme is planned to utilise this irrigation discharge in full for generation of power. Studies revealed that it will not be possible to utilise the vents in the sluices to avail of the full potentialities of the entire irrigation discharge as the power draft that could be drawn through each vent at the specified turbine inlet velocity will be comparatively low due to the sizes of the vents already constructed. The present proposals is therefore to draw the entire irrigation discharge through a tunnel located in the left flank 600 ft. away from the dam and utilise this for power generation in a station to be located on the left flank of the river below the dam. This power station will be called the Mettur tunnel power station to distinguish it from the existing one.

HISTORY

A scheme estimated to cost Rs. 13,32 crores for power development utilising the full irrigation discharge by installing four units of 50,000 kW each was formulated and forwarded to the Government of India in November 1957. The C.W.P.C. deputed Dr. K. L. Rao to study the scheme and after inspection at site and discussions with officers of the Department, he recommended that the scheme may be taken up in two stages. In the initial stage there will be only two units of 50,000 kW. All the civil works like tunnel, surge shaft, power station etc. will however be built for the ultimate utilisation of 200,000 cusecs. Two more units will be added at a later date. A revised report was prepared envisaging an installed capacity of 100,000 kW and incorporating certain suggestions made by Dr. K. L. Rao. The revised scheme estimated to cost Rs. 599 lakhs was submitted in February 1959.

This was approved by the Planning Commission and was sanctioned in May 1960. Even though this scheme has been included only in the Third Five Year Plan, the Planning Commission, as a special case, have agreed for taking up the preliminary works not involving foreign exchange during the current plan period itself. The scheme was inaugurated on 30th August by Sri K. Kamaraj, Chief Minister of Madras.

PROPOSALS

The sketch showing the plan and profile of the scheme is given elsewhere. The scheme comprises mainly of the following:

(1) A leading channel of about 500 ft. in length cut on the foreshore of the Mettur reservoir terminating at the tunnel intake.

(2) A concrete lined pressure tunnel of 45 ft. dia and about 1350 ft. long and a surge shaft about 200 ft. deep.

(3) Four penstock tunnels each to accommodate penstock pipes of 21 ft. 6 inches internal diameter.

(4) A power station initially with two vertical Francis turbines each coupled to 50,000 kW generators with step up transformers and associated switchgear.

(5) A transmission system of 110 kV and 230 kV lines to link the new power house with the existing grid.

SALIENT FEATURES OF THE SCHEME

Leading Channel:

The leading channel from the bed of the reservoir will have a bed width of 70 ft. near the intake with concrete pavement for a distance of nearly 100 ft. It will be gradually widened towards the

lake side and will be about 100 ft. where the concrete pavement commences. Beyond this the channel will be cut upto a point where the ground level is+670. A course screen will be provided at the junction of the channel and the commencement of the tunnel.

Tunnel:

The tunnel will be located between the Dam and Ellis surplus saddle on the left flank and about 600 ft. from the Dam and about 100 ft. away from the right abutment of the Ellis' saddle. The sill of the tunnel is fixed at +645 and that of the leading channel at +670. A slope of 25 ft. is given in the leading channel within a distance of 500 ft. A coarse screen grill with heavy rolled steel joists spaced at about 3 ft. and 6 ft. centres will be provided at the mouth of the tunnel to avoid any huge floating materials getting into the tunnel and chocking the water way. Fine screens are however provided in the surge shaft in front of the penstock intake.

The tunnel 1350 ft. lond and 45 ft. internal dia will be of circular shape and cut in rock. The entire length will be lined with cement concrete, the thickness of concrete lining ranging from 2 ft. to 4 ft. 6 in. The maximum discharge in the tunnel will be 20,000 cusecs.

Surge Shaft:

The tunnel ends in a surge shaft 200 ft. deep which will be lined with cement concrete for the entire depth and floor. The surge shaft will be semi-circle in shape and of diameter 154 ft.

Penstocks:

Four steel lined penstock tunnels will take off from the surge shaft. Initially only two penstock pipes are being laid. Each penstock will be designed for a discharge of 5,000 cusecs. Two more pipes will be added later on. The penstocks which will of 1" thick steel plates will have an internal dia of 21 ft. 6 inches. Separate inspection galleries will also be provided over the penstock along their lengths with an inter-connection near the surge shaft end. Each penstock will feed an individual turbine in the power house.

Power House and Transfomer Yard

The power station will be built to accommodate four 83,500 H.P. Francis turbines each coupled to 50,000 kW. generator. Initially only two units will be installed. Power will be generated at 11 kV 3 phase 50 cycles and stepped up to 110 kV for linking up with the existing Mettur Power House, and at 230 kV to feed into the Grid at Salem. There will be initially two 55,000 kVA 11 kV/110 kV Transformers and two 55,000 kV 110/230 kV auto transformers. Each of the generators will be directly connected to its power transformer and operated on the unit system. The transmission system will include one span of 110 kV single circuit line from the tunnel scheme power house to the existing power house which is very closely situated and 25 mlies of 230 kV single circuit line from the tunnel scheme power house to the existing Salem 230 kV substation.

ESTIMATED COST

The estimated cost of the sanctioned scheme works out to Rs. 507.78 lakhs initially rising to Rs. 598.80 lakhs at the end of the four years. A net revenue return of 15.8% is expected even from the fourth year of the operation of the scheme.

RUSSIAN AID

The Mettur tunnel scheme has been included by the Government of India among other schemes for Russian assistance. A Soviet delegation visited the site for on the spot study in May this year. Copies of specifications prepared by the Department for generating machinery transformers, transmission lines, substation equipments, gates, penstocks etc. were given to them. The two units 50,000 kW each will be delivered in two years time from the signing of the contract. The firm offer from Messrs. Machinoexport, Moscow is expected soon.

CONCLUSION

Even though power can be generated only during the irrigation period of seven months, by a careful integrated operation of the Grid, the full energy potential of 385 million units will be utilised. During this period when the Mettur tunnel power station is in operation, the storages in Kundah and Pykara basins will be conserved for utilisation in the non-irrigation period.

The completion of this project will thus go to improve the power position in Madras State to a large extent and enable the department meet the demand for industries and also extend electricity to additional villages.

TECHNICAL DATA

The following are the salient particulars of the Mettur Tunnel Scheme.

Tunnel Intake

1. F.R.L. of Reservoir (Present)	+790.00
2. F.R.L. of Reservoir (Future)	+800.00
3. Minimum Draw Down Level.	+720.00
4. Sill level of tunnel at commencement	+645.00
5. Sill level of leading channel at tunnel entry.	+670.00

Pressure Tunnel

1. Maximum Discharge (1st Stage)	10,000 Cusecs.
2. Maximum Discharge (IInd Stage	20,000 Cusecs.
3. Inside finished dia. of tunnel.	45'—0".
4. Shape of tunnel.	Circular.
5. Area of water way.	1,590 Sq. ft.
6. Velocity in tunnel for 10,000 cusecs.	6.29 ft./Sec.
7. Velocity in tunnel for 20,000 cusecs.	12.58 ft./Sec.
8. Head loss for 10,000 cusecs.	2'—0".

9. Head loss for 20,000 cusecs. 6′—0″.
10. Length upto surge shaft 1,350.
11. Ground level at Commencement of Tunnel 731.00 (Approx)
12 Crown of tunnel at intake. +695
13. Slope of tunnel from intake to entry in surge shaft. 1 in 193 (7′—0″).
14. Sill of tunnel at inlet into surge shaft. +638.00
15. Crown of the tunnel at surge shaft +683.00
16. Thickness of concrete lining:—
    (a) From Ch. 00 to Ch. 470 R.C.C. Lining 4′ 6″ thick.
    (b) From Ch. 470 to Ch. 1275 R.C.C. Lining 2′ 0″.
    (c) R.C.C. Lining 3′ 0″ thick.

Surge Shaft

1. G. L. at Location of surge shaft. +850.00
2. Top of shaft „ +835.00
3. Bottom of shaft „ +628.00
4. Maximum surge level „ +831.25
5. Minimum surge level „ +678.00
6. Inside dia (semi circular) 154′—0″
7. Distance between tunnel and end of gate piers. 77′—0″
8. Thickness of R.C.C. concrete lining Minimum 12″.

Gates and Screens in Surge Shaft

(a) *GATES*

1. Number of regular gates. 4
2. Number of emergency gates 4
3. Size of regular gates 18′—0″ × 26′—6″.
4. Size of emergency gates 18′—0″ × 34′—0″.

(b) *SCREENS*

1. Number of screens 4.
2. Size of screens (fixed type) 25′ 0″ × 80 0″

Penstock Pipe Tunnels

1. Number of penstock pipe tunnels. 4.
2. Size of penstocks. 21′—6″
3. Size of tunnel to accommodate penstock with minimum 18″ concrete lining around. 24′—6″ dia.
4. Discharge in each penstock 5000 cusecs.
5. Velocity in penstock for 5000 cusecs. 13.77′/Sec.
6. Head loss for 5000 cusecs. 2.84′.
7. Total head loss for 10,000 cusecs discharge in tunnel 4.84′.
8. Total head loss for 20,000 cusecs discharge in tunnel. 8.84′
9. Sill of penstock pipe tunnels +638.00
10. Length of penstock tunnels 300′
11. Slope of penstock tunnel 1 in 40 (7′ 6″).
12. Size of concrete lined inspection gallery over each penstock. 4′ 0″ × 6′ 0″.
13. Size of the concrete lined connecting gallery of the above inspection galleries near the surge shaft end. 4′ 6″ × 6′0″.
14. C. L. of penstock at turbine inlet +639.50
15. Dia of air pipe 7′—6″.

Power House

1. Number of generating sets. Initial 2. Ultimate 4.
2. Capacity of each generator 50,000 KW.
3. Types of machine Vertical.
4. Type of turbine Francis or Kaplan.
5 Horse Power of turbine 83,500
6. Maximum gross head on turbine 160′
   Minimum gross head on turbine 80′
   Average head 130′
7. R. L. of C. L. of Distributors +639.50
8. Power House Floor level +660.00
9. Maximum Tail Race W. L. +648.00
10. Normal Tail race W. L. 634.00
11. Minimum Tail race W. L. +631.00
12. Draft tube bottom level +595.00
13. Energy output per annum
    Initial 385 million units
    Ultimate 587 „ „

Transmission System

Mettur Tunnel Power Station—Salem 230 KV S. C. Line. 25 miles.
Mettur Tunnel Power Station—Mettur Power Station 110 K.V. S. C. Line. 1 span.

Estimated Cost

Rs. 507.78 lakhs initially rising to Rs. 598.80 lakhs (at the end of first stage).

NOTICE

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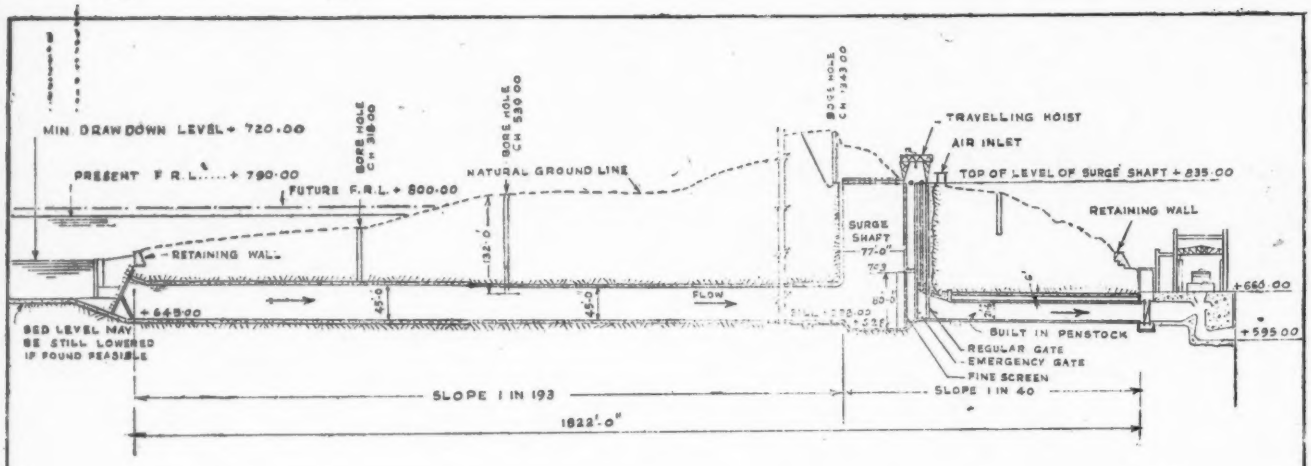

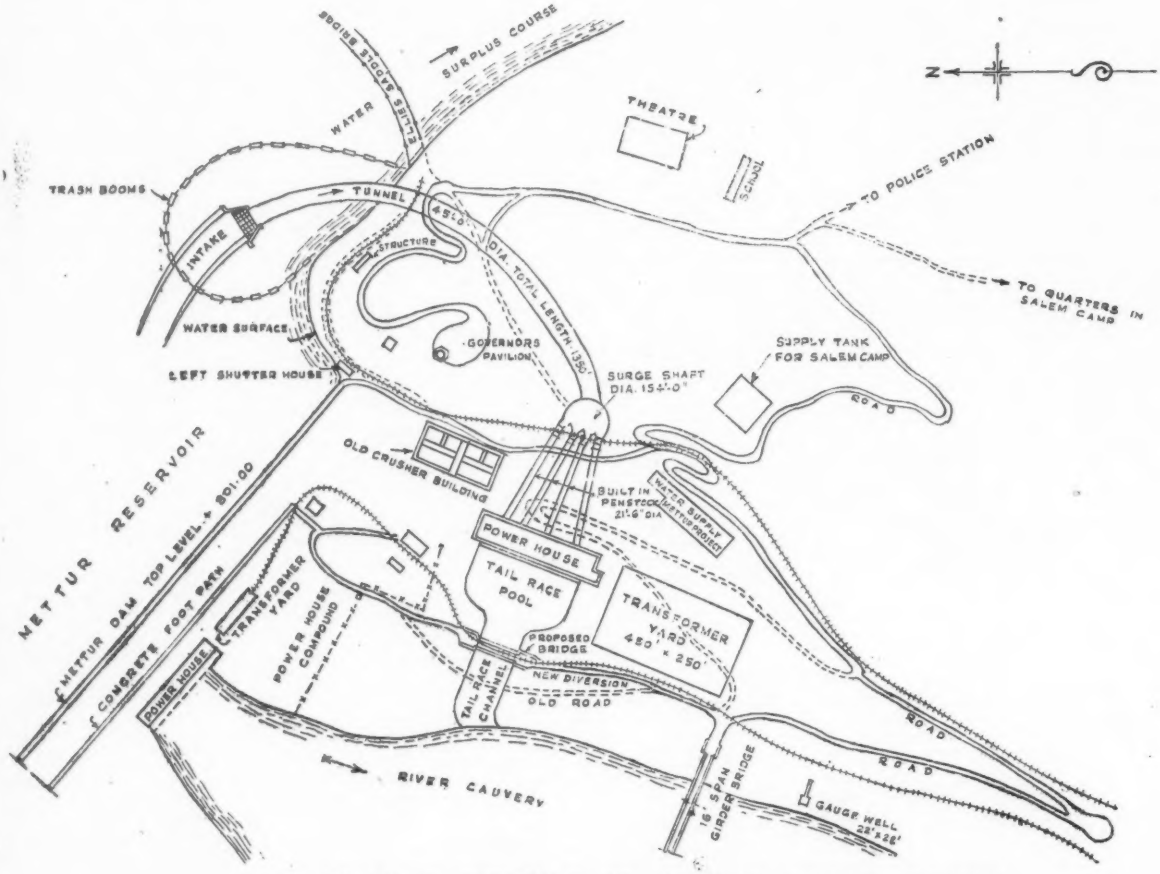

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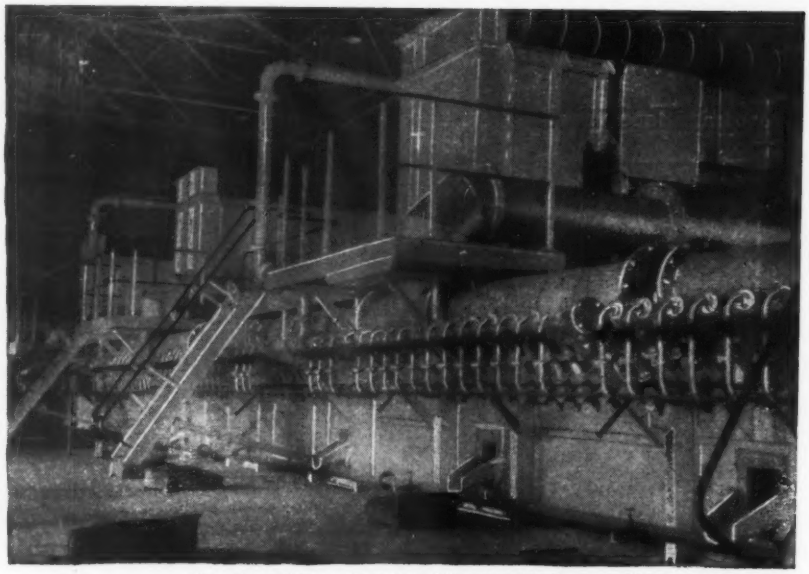

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Modern Methods of Site Investigation and their Limitations

By B. S. SATHYA NARAYANSWAMI

Geological conformation of a site in most cases of civil engineering undertakings affect the design and construction methods. The geological investigation of a site is almost universal at present in major undertakings. Foundation conditions are essentially geological conditions. To have a thorough three-dimensional picture of foundation conditions geological investigations are supplemented with modern methods, such as aerial surveys, soil mechanics and geophysical methods. The knowledge of possible geological conditions of a site is an essential prerequisite to select the most suitable methods and to aid the interpretation of their results for a rapid and economical investigation. The more important methods and their limitations are discussed and the importance of a close cooperation between geologists and engineers in site investigation is emphasised.

Geology is the science of the earth, more particularly it is the study of the nature, structure and history of its upper accessible part called the 'crust' of the earth, which is made up of a variety of rocks and minerals of varying density and rigidity, magnetism, electrical resistance and elasticity.

Civil Engineering constructions and river valley development projects require services of geology for their efficient, economical and successful completion and functioning, as the structures are only as safe as the foundation on which they rest and the materials of geologic origin, natural or processed from which they are constructed, which in turn are governed by the geologic conditions, processes and forces acting on them.

Civil engineers rely on the methods and techniques of geological sciences which contribute in solving problems connected with foundations, building materials, construction of railways, highways, and bridges as well as waterways harbours and airfields, siting of dams and tunnels, drainage and underground power stations.

In the selection of a site for a structure the construction engineers or the contractors seldom have adequate knowledge of the subsurface conditions. In most cases the design and methods of construction are largely dependent upon the local geological conditions and available materials. Many important structures are in danger because of the oversight of the significance of subsurface geologic conditions. Engineering history is marked by failures of structures like dams, bridges and buildings in most cases due to failure of rock or soil in the foundation or the use of faulty materials of geologic origin, the inherent weakness of which were not appreciated due to lack of geological investigation of any kind.

However, the geological investigations and predictions are not cent per cent correct in all cases and in order to construct a thorough three-dimensional picture of subsurface geologic conditions geological investigations are to be supplemented by certain suitable modern methods. The chief methods which have drawn the attention of civil engineers for site investigation in conjuction with geological methods are aerial surveys, soil mechanics and geophysical methods.

An attempt is made to describe and discuss in this paper briefly the principles of modern methods and to show how they are dependent on a preliminary geological survey and also how these methods are to be used with discretion for a rapid and economical site investigation.

Variations in Subsurface Geology

The geological conformation of the earth's crust is such that the rocks are seldom uniform for any considerable extent. They change laterally and vertically both in composition and structure governed by mineral alteration, deformation and defects.

In construction practice three types of ground conditions are met with governed by geological features and processes.

1. *Solid rock* may exist at the ground surface or so close to it as to render possible the founding of a structure directly on it :

2. *Bed rock* may exist below the ground surface at a considerable depth that may be economically reached by a practicable type of foundation so that the load of the structure can be safely transmitted to it : and

3. *The hard rock line* or the nearest solid rock may be so far below the surface that it cannot be used as a foundation bed.

The first type is the safest and the investigation is limited to reveal the soundness of the rock formation, its extent, and for the allowances to be made for seismic disturbances. Compression tests can be made on specimens by loading in a direction corresponding to that at the site.

Thorough subsurface exploration is necessary in

the second and third type of gound conditions to determine the geological conditions of the beds and defects, soil and subsoil characteristics as well as ground water conditions as all foundations ultimately derive their support from the underlying soil or rock.

Current practice of site investigation is to drive a series of trial pits and boreholes to the bed rock or to such depths that piles could be driven to support foundations, and the bearing capacity is calculated from empirical formula based on assumptions. In most cases the bearing capacity and the impermeability of the commoner soils and rocks are generally sufficient but difficulties arise due to various defects in them which diminish their physical strength.

The common defects and deformation noticed in the foundation beds are cracks, fissures, joint systems, and faults bedding, folding, thrust and shear zones, zones of deep weathering, cavities and solution channels, burried channels and lava tunnels, igneous-intrusives as well as porosity or permeability. These defects have detrimental effects on foundations and are responsible to a greater extent in the variations of the fundamental properties of the earth, viz., density, rigidity, magnetism, electrical conductivity and elasticity, and the ground conditions of a given site.

Geological investigations

The surface features of a site are often misleading. Geological processes might have materially altered them to appreciable depths below the surface. Therefore the first essential thing in starting a site investigation is to make a geological survey to determine the possible subsurface conditions.

Geological investigations customarily fall into three stages.

1. A *Reconnaissance* or preliminary investigation which confines to a brief study of the physiography, distribution of rocks, their structural features and visible bed rock geology, permeability, dip and strike, their amount and direction, and the visible defects such as faults, joints, open or filled up fissures as well as overburden characteristics.

2. *Geological mapping*: A thorough large scale geological mapping provides much of the geological information to base plans for detailed exploration, design and construction. Geological maps also help investigation and consideration of natural construction materials such as gravel, sand and earth, and also potential quarries available at or near the site.

3. *Exploration* of special features such as extreme irregularities, chemical alterations, intercalation of soft beds and fracture zones, water bearing horizons, perched water table and ground water conditions, and depth to bed rock concealed by thick over-burden by trial pits, drifts and core drilling.

Core drilling :

For large structures accurate assessment of subsurface geologic conditions and the strength of their foundation is essential. This can be achieved by getting rock samples from different depths, called core samples as they exist in situ and subjecting them to various tests. By this it is possible to determine the sequence of rock formations underground, their thickness and dip and strike. Generally it is possible to determine the general attitude of the strata by three holes at 100—200 ft. apart in two directions at right angles to each other. But for a thorough subsurface exploration and in geologically complicated areas, in order to determine the faults folding, weak zones, joint pattern etc., several holes are put in according to definite plans and to depths as suggested by competent geologists. Core drilling is carried out in many different ways such as :

i. Diamond drilling
ii. Calyx or shot core drilling

according to the choice of the experts or equipment.

These investigations help to construct fairly accurately the subsurface geologic profiile in order to understand the essential foundation conditions. Large diameter i.e., 36″-40″ borings allow visual and periscopic inspection. All specific tests are carried on core samples. Details of geological investigations are given elsewhere by the author.[10, 11]

Very often in conspicuously bad ground and also as a reconnaissance survey is doubtful as well as inaccessible terrain aerial observation and geophysical methods are carried out. In areas where earth conditions predominate or where structures are built with earth soil mechanics methods are applied both for site investigation and to determine the soil characteristics.

Aerial Surveys

Aerial surveys are done in two ways. First a preliminary reconnaissance flight over the site by a team of geologists and engineers. Secondly photographs are taken of the terrain from air and details in the photographs are interpreted properly in conjunction with ground surveys and both topographic as well as geologic maps are prepared out of them to scale.

Aerial Reconnaissance :

For a preliminary observation of a site aerial reconnaissance is ideally suited. This is especially so when the terrain is virgin, inaccessible and where are no better communication. Aerial reconnaissance is done by observing the terrain conditions from an aircraft or a helicopter controlled by an experienced pilot. A team of geologists and engineers fly together as passengers and observe and sketch terrain features, each on his own base map. Thus facilitating comparison and correction of the results later. By this it is possible for the geologists and engineers to pick out those places which they think require special investigation on the ground. They also take snapshots of the parts of terrain over which they fly

which assist for future detailed interpretation of the site conditions and of surrounding areas.

Aerial Photography :

Aerial photography has revolutionised the methods of large scale reconnaissance surveying and preliminary mapping. It helps to trace the contour lines and to determine the nature of the soil, rocks, soil erosion and vegetal cover with great speed and accuracy. The fact that aerial photographs give a wider view than ground views aids the general geological interpretation of the area, as such aerial surveys are of great benefit when they are supplementary to or supplemented by comprehensive ground surveys.

The uses of aerial photography are innumerable. They are invaluable in their application to civil engineering, mining, and in many branches of geology.

At present for a complete geological investigation the existing topographic maps do not serve as base maps as the bare outlines of geologic structures will not meet the needs of design and construction engineers. The methods of aerial surveys and their interpretation so far as site investigation in concerned are described below :

The study of aerial phographs and of maps conconstructed from them for geologic information and investigation is called *Photogeology* and the technique of obtaining reliable measurements by means of aerial photographs is called *Photogrammetry*.

There are two general methods of aerial photography :

1. High altitude aerial photography to obtain birds eyeviews for descriptive purposes, and
2. Low altitude aerial photography to obtain vertical views for mapping.

Birds eye views are of great value in illustrating preliminary reports, enabling geologists and engineers to visualise rapidly and clearly the nature of the proposed sites. The birds eye view photographs are called *obliques* and if they include horizon at distance they are described *high obliques* and if they do not include the horizon they are described *low obliques*. (fig. 1 and 2).

Vertical views are called *verticals*. They are taken usually from altitude 500 to 1500 ft. with the camera pointing vertically downward. (Fig. 2). The verticals are extremely useful for geologists and engineers to prepare accurate maps, cross sections and profiles of the site and to plan subsequent detailed investigations.

Aerial photographs always exhibit some distortion and errors mainly due to difficulties in flight conditions as well as due to obstructions by the wings or the tail of the aircraft. And also the views are all perspective and flat. Experience has shown, however, that a focal plane shutter camera gives better and sharper pictures. When the aerial photographs are tied to a ground control, corrected for scale, tilt and perspective distortion they are called controlled photographs.

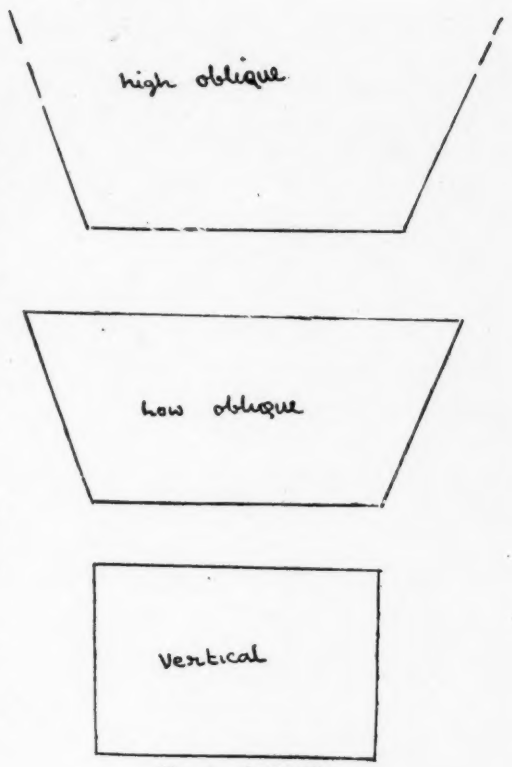


Fig. 1. Aerial Views.

METHODS OF STUDYING AERIAL PHOTOGRAPHS :

Aerial photographs may be simple contact prints or stereopairs.

Photostrips, photo mosaic or composites :

These are flat contact prints or enlargements and show no relief. These serve as aids to determine the local features of the site such as roads, railways, houses, water, vegetation, streams and rivers, slopes etc., which appear in patterns. Well graded highways appear with sharp angular turns, railways always curved, houses, buildings and trees appear conspicuously by their characteristic shadows. Still water appear black or dark grey, otherwise look white or light grey. Stream and river courses, commonly branch headward and dendritic indicating the direction of general slopes. Soil, vegetation, cultivated fields etc., have various tones and characteristic appearances. These photographs also serve as base maps on which to enter geologic data to carry out subsequent investigations.

Most of the aerial photographs are a series with some overlapping—usually 60 per cent—of common details. Such a series of overlapping photographs constitute a photo strip. An assembly of vertical photographs taken from parallel adjacent flights matched and mounted on a firm flat base like a

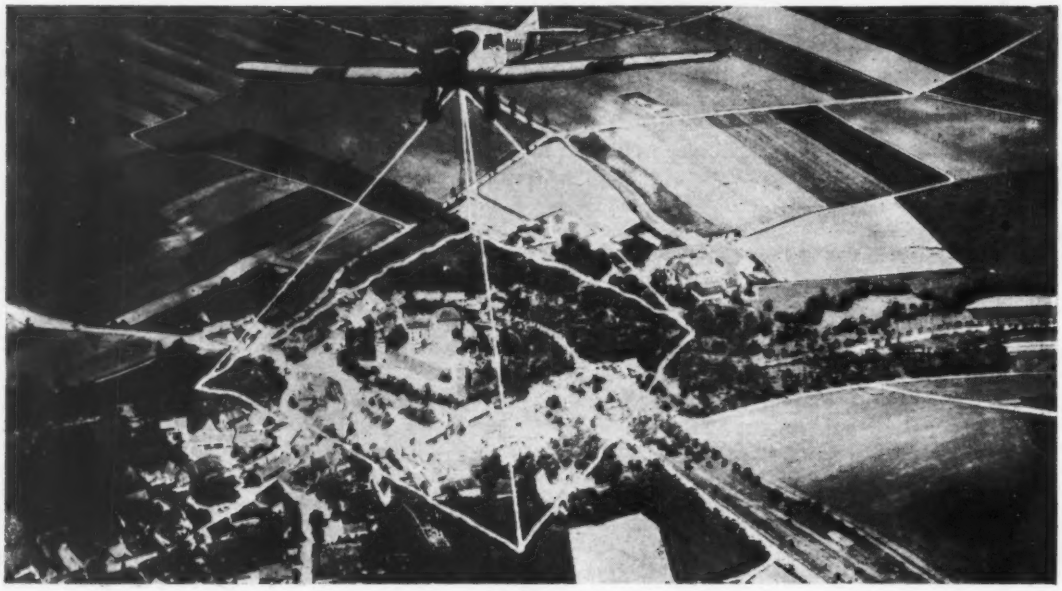


Fig. 2. Aerial photography.

masonite board in such a way that they will completely cover the area on a chosen scale is called a photo-mosaic or a mosaic or a composite. A recopy of such a mosaic is called a final mosaic which may be a reduction or an enlargement of the original. (Fig. 3).

Stereopairs:

A pair of photographs of the same area taken

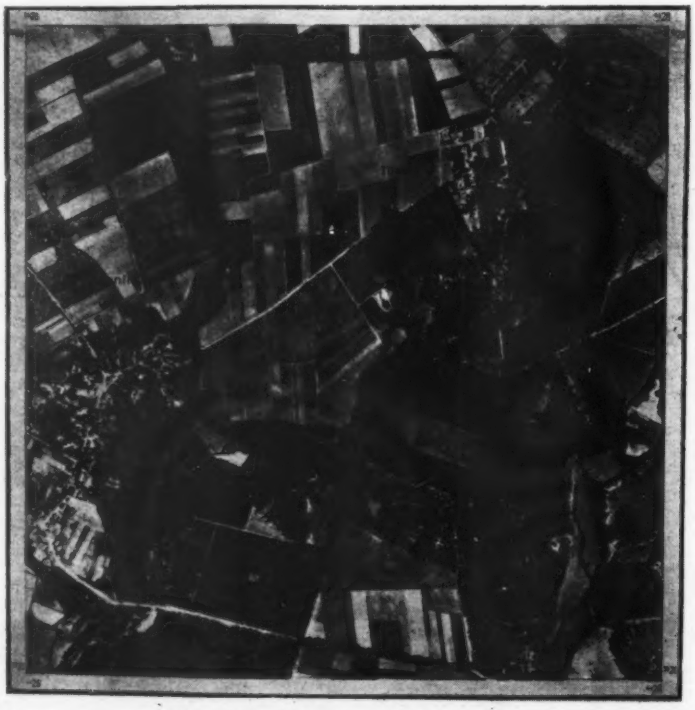


Fig. 3. Photo Mosaic—Air photo plan 1: 5000

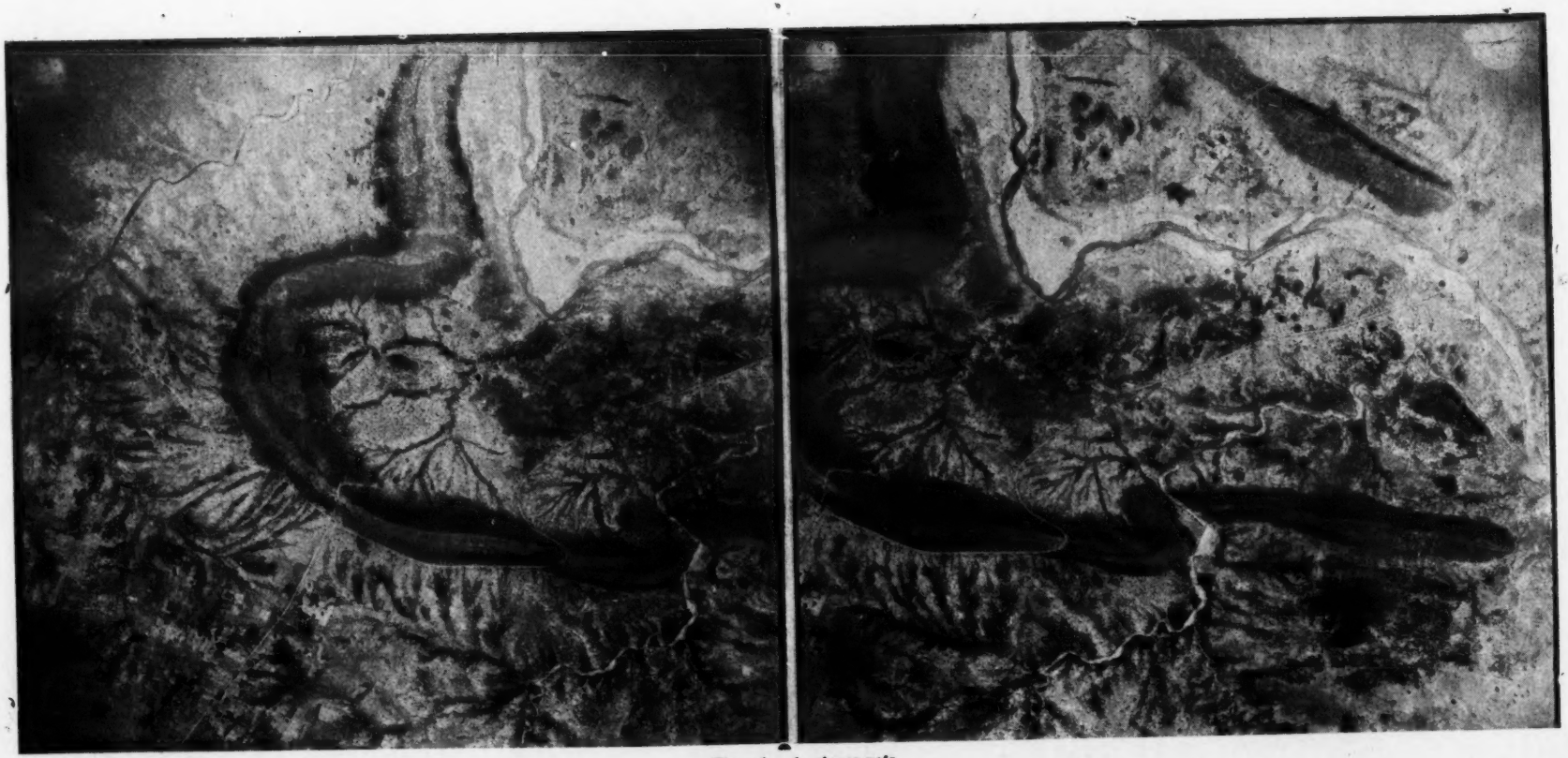


Fig. 4. A stereo-pair.

from somewhat different view points or by means of a stereo-camera when superimosed produce a three-dimensional effect i.e., the elevations spring up and stand out in relief in the picture (an optical illusion). Such a pair of overlapping photographs is called a stereo-pair (fig. 4) or a stereogram. A stereo-pair is always studied for purposes of interpretation under an instrument called a stereoscope.

Stereoscopes:

There are two kinds of stereoscopes.

1. Reflecting mirror type called Pellin stereoscope (fig. 5).
2. Lens type foldings stereoscope. (fig. 6)

Fig. 5. Pellin Stereoscope.

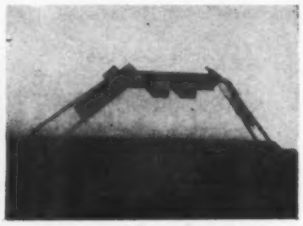


Fig. 6. Lens type Folding Stereoscope.

The Pellin stereoscope consists of four mirrors, two small and two large set at 45° to the plane of the base of the instrument on which the stereopairs are fused, in a rigid metal frame. The lens type has two lenses with some magnification, usually × 2.5, one for each eye. The principle of stereoscopic observation is essentially the same as vision by two eyes that see the same object in slightly different directions i.e., binoccular vision.

The area of overlap within which the three-dimensional effect is seen when a stereopair is viewed under a stereoscope is called the spatial model or simply the model.

Map compilation:

The transfer of data from aerial surveys and from partially or wholly controlled aerial photographs and composits to two dimensional or planimetric base maps and contour maps (fig. 7) is done by a simple photogrammetric instrument called Universal sketch-master or Air-photo transformator (fig. 8) which is essentially a camera lucida in principle and the corrections are accomplished for parallactic distortion by any of the several radial plot or radial line methods based on common surveying principles of intersection and resection in trangulation.

Photogeology:

Aerial photographs are of immense value in the interpretation of geologic structures and their subsurface expressions. They give a fair idea of the nature of the site that is to be traversed geologically. Preliminary stereoscopic examination of stereopairs permits the geologists to select features of special

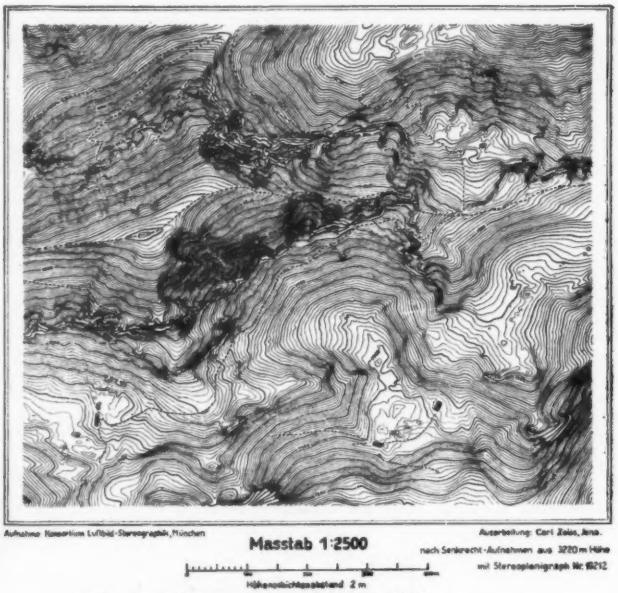


Fig. 7. Plotted Contour Map 1: 2500.

interest that may require careful and detailed investigation at the site. Outcrops, their nature, inclination and folding of the strata as well as escarpments and the direction of dip and strike and slopes can be very easily made out by trained eye from the bowing of contacts and beds in the valleys. Dips observed under the stereoscope appear steeper than the true dip at the site. However, dips can be accurately estimated after some practice with actual checking on the ground.

Anticlinal and syniclinal folding or their limbs are recognised easily by observing the trend of the strata and their down dip bowing in the valleys which show up very well in the photographs. Faults, shear zones and thrust zones and joint patterns as well as joint systems show up strikingly in the aerial photographs which otherwise are often inconspicuous on the ground. Similarly landslides, sinkholes and others can also be readily recognised.

The structure-contour maps of rocks which are essential for dam site and tunnel location studies can be produced by superposing under a stereoscope a photomap on which geological boundaries have been drawn with another identical photomap on which topographic contours have been drawn.

Further aerial photographs aid geologists to plan location of bore holes properly to get the core samples and to assess the conditions of the foundation materials and their strength and also to recommend suitable geophysical exploration.

Thus aerial surveying is a well grounded system of map making the results of which surpass the conventional methods of surveying and mapping in fidelity and completeness of details obtained and

Fig. 8. Air Photo Transformation Apparatus
Fig. 9. Stereo-comparator.
Fig. 10. Stereo-Autograph.

also in economy both in money and time. However, there is some limitations to this method. Aerial survey mapping is readily adapted to regions of moderate relief, but deep canyons, gorges and precipitous mountains introduce awful and troublesome distortion. As such this method is not particularly suitable for mapping such features although it is the only method for a reconnaissance survey over such terrain. Yet it is best suited for catchment area and reservoir site surveys in mountainous regions as large parts of the adjacent mountains need not be shown. A valley or a canyon presenting a series of alternative sites for dams for instance, can be best studied by means of stereopairs.

Recent improvements in photographic equipment and technique and also the introduction of modern accessories such as telephoto and wide angle lenses have resulted much more accurate results with stereoscopic observation and the more precise instruments like stereo-comparator (fig. 9) and automatic plotting machines such as stereo-autograph (fig. 10) have enabled the scope of the aerial surveys much more increased.

For engineering site investigation photogeologic studies furnish basic data and for purposes of studying and interpretation of geologic conformation and features for location of roads, railways, bridges and pipe lines. Apart from major engineering undertakings and multipurpose river basin development projects, for purposes of town planning or reconstruction after bombardment, or earthquake or flood disaster, a general picture of the existing conditions together with some idea of the possible trend of social and industrial development, communication facilities and the related soil, vegetation and geologic conditions and features can also be had from aerial surveys.

However, so far as site investigation is concerned, if good topographic maps are available and the surface geology is fairly well known, it is quite possible to dispense with aerial survey mapping.

Soil mechanics methods

Soil mechanics to define briefly as applied to site investigation is the study of the capacity of a soil (engineering properties) to withstand the use to which it is put. On opening an excavation for a foundation the pressure acting on the soil below the excavation is reduced and the soil heaves upward. On laying the foundation course when the structural load becomes equal to the weight of the soil removed the settlement will be roughly equal to the heave, the original state of stress having been restored. The foundation at this stage will be fully buoyant and the net pressure is zero. Continued structural loads due to further construction increase the stresses in the soil beyond their original values. Foundation failures in general are due to a yield at this juncture of the underlying soil, but if the settlement is uniform over the area of the structure no serious damage is likely to occur.

Thus, unless the effects of loads on soils and the behaviour and the ability of different soils to withstand external loads or the forces induced in them by such loads as roads, railways aerodrome-runways, bridges and dams as well as various kinds of buildings are fully understood and the structures

designed to suit the site conditions or improve the ground conditions accordingly either waste of money due to too conservative a design or structural damages result due to unequal settlement, like the classic examples of the leaning tower of Pisa, many ancient stone temples of India and failure of portions of Panama canal.

Soil Investigations:

Soil mechanics methods mainly follow a pattern of Sampling—>Testing—>Analysis—of soils and consist of,

1. Investigation of soil conditions as they exist in situ,
2. The classification and testing of properties, and
3. The application of various theories and practices which have been verified against experience in order to predict the soil behaviour.

The predictions of soil behaviour is therefore dependent on

1. Representativeness of the soil samples
2. The pertinence of the testing, and
3. The pertinance of the theories and assumptions used in the analysis.

Thus soil mechanics techniques involve in

1. obtaining information regarding the type, sequence, thickness and dip of the strata,
2. procuring soil samples—both undisturbed and disturbed—for laboratory tests and identification purposes, and
3. determining the natural water content in soil and the general ground water conditions of the site.

The amount and extent of exploration depends on the information and data available from various other sources. Data on the type, sequence, thickness and dip of the strata and general ground water conditions can be obtained readily from bore holes and geological investigations, records, and maps as well as from geophysical methods.

Sampling:

Soil samples are of two kinds.

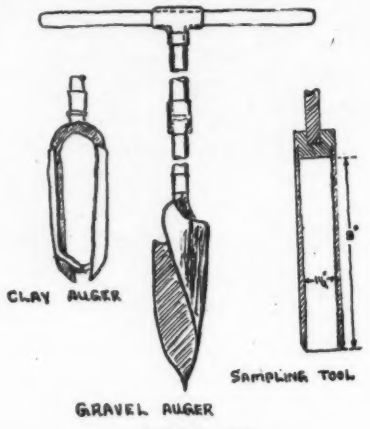
1. Undisturbed samples: in which the intergranular relationships are preserved,
2. Disturbed samples: in which the in situ conditions are disturbed.

Samples are obtained from each change of soil strata and to sufficient depths. The rule of thumb is to carryout investigation to a depth of at least one and a half times the width of the structure.

Soil samples upto 10 to 20 ft. are obtained by trial or test pits and screw augering. From the samples the nature of the top soil can be easily determined. But the cost and difficulty of obtaining samples by test pits increase rapidly with depth.

Undisturbed samples are obtained from depths upto 30 ft. by a post-hole-auger equipment (fig. 11).

Fig. 11. Post-hole Auger Equipment.



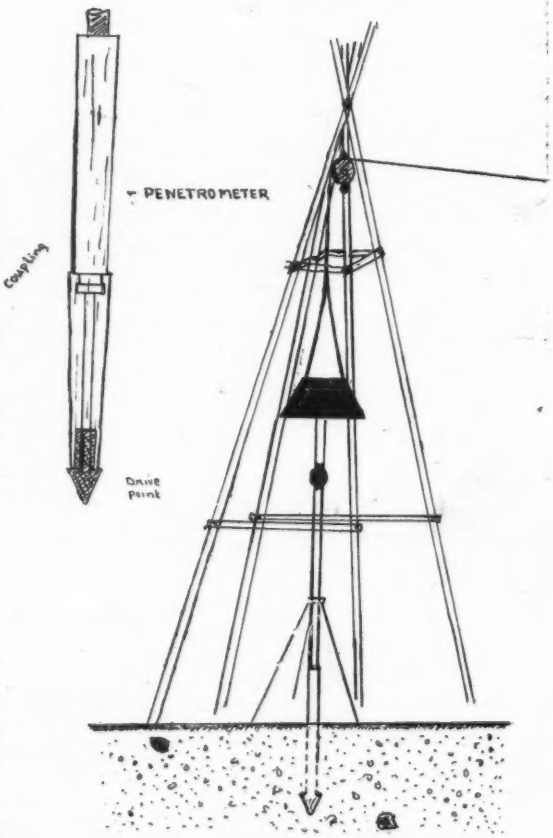


Fig. 12. Penetrometer probing Equipment.

The equipement consists of a screw auger which is turned and drove in by means of a tee-piece handle through an extension rod. As boring proceeds a small metal sampling tube is pushed into the ground

at the bottom of the hole to procure undisturbed sample. The sample is well protected with paraffin wax to preserve the natural water content. For clay and gravel different types of augers are used.

Testing:

Sample testing is two fold:

1. Field testing, and
2. Sample testing

Field Testing

This is measuring soil properties in field *in situ* by driving penetration cones, test piles and other resistance devices into the soil and thereby determine the bearing capacity of the soils.

Penetration Testing:

1. Penetrometer probing.

In cases where hand boring is difficult and laborious chistling, hammering, air or water jetting are resorted to. An interesting and useful technique in such cases is 'penetromer probing'. The penetrometer equipment consists of a conical point, 2 in. dia. × 2¾ in. high, a slightly tapering bottom rod 1½ in. dia. at the bottom, 1¾ in. dia. at the top and 3 ft. long and a number of extension rods 1½ in. dia. × 6 ft. long, a 100 lb. standard driving weight, a guide rod for the driving weight and a tripod or sheerlegs and pulley assembly. (fig. 12).

The conical shoe is slipped on to the bottom rod and is driven down by blows from the 100 lb. weight falling through 24 or 30 in. As it is driven into the ground, the number of blows required for every foot of penetration is counted and recorded. It is driven down through soil till the case of penetration is resisted by a hard surface such as a boulder or bed rock. A graph showing the rate of penetration against the number of blows is drawn for each probing and this gives an idea about the compaction of soil at different depths. But presence of boulders and increase of frictional resistance limit the accuracy of this test.

2. Standard penetration test.

In order to obtain a more accurate data regarding the resistance to penetration, compaction and bearing capacity of the soil at a particular depth a standardised penetrometer working inside a casing pipe is used and the method is called 'Standard Penetration Test'. To determine the compactness of the soil a casing pipe is driven to that depth and the pipe is cleaned by scooping and washing. A sampling spoon 1½ in. dia. × 2'8" long with a slit on the side to collect the soil sample and a conical shoe is lowered to the bottom of the casing pipe and is driven down through the soil by blows from a 140 lb. standard weight falling through 24" or 30". The number of blows for one foot of penetration is recorded which is a measure of the compactness and the bearing power of the soil at that depth. This test is repeated for every 5 ft. depth down to bed rock.

Terzaghi recognises the following types of soil on the basis of data from standard penetration test:

1. Less than 4 blows—very loose soil
2. Between 4 and 10 blows—loose soil
3. Between 10 and 30 blows—Medium soil
4. Between 30 and 50 blows—Dense soil
5. More than 50 blows—Compact or very dense soil

In addition, by means of a number (generally hundreds) of such probings and tests the general lie of the hard rock surface can be located and its contours can be drawn and mapped. However, often the results are desceptive and must be correlated with data from other sources.

Sample testing:

Sample testing includes

1. classification tests for index properties
2. basic properties tests for indirect application
3. empirical properties tests for direct application.

The value of classification tests is for purposes of correlation and record. Grain size is the main criteria and also the convenient basis for the classification of soils for engineering requirements. The grain size or particle size distribution is determined by mechanical analysis. The particle size distribution and also other index data like liquid limit, plastic limit, and shrinkage limit (called Atterberg limits), when tied with observations of soil performance help to build up an empirical understanding—soil mechanics specifications—for foundation designing.

Analysis

The attendent engineering problems on which soil mechanics has an important bearing can be grouped as :

1. Stability problems, and
2. Deformation problems.

1. The stability problems are those in which over stressing produces rupture or failure of soil i.e., concerned with strength properties like slope stability, earth pressures, and bearing capacity. The basic properties tests help to determine the isolated soil properties which have a direct bearing on the soil behaviour. The Triaxial compression test for instance is a good example of the basic properties test where in a cylindrical sample of soil is stressed axially under controlled lateral confinement. This type of soil test gives information about cohesion and angle of internal friction (strength moduli) which are applied to the analysis of stability problems.

2. The deformation problems are those in which moderate stresses produce only deformation of the soil, therefore concern with changes in shape and volume of the soil due to its own weight or to external loads or seasonal weathering. Thus at the end of a construction the net settlement will be made up of two parts : (a) the immediate settlement due to deformation of soil taking place without volume

change and (b) consolidation settlement due to extrusion of pore water and therefore a volume change.

And the value of the emperical tests lies in the emperical correlation between field performance and test data. The values of net settlements resulting from the increase in the net foundation pressure are calculated in the methods of settlement analysis. "The Proctor Compaction Test" for instance, is used to determine the compaction properties of soils. By this test the optimum moisture content for maximum density in soils is determined by pounding representative soil samples with different moisture contents into a cylindrical mould with a standard weight dropped from a standard height.

The data from this test are applied directly in construction. This test is also useful to determine the compaction properties of soil when used as a fill.

Soil mechanics techniques have been tremendously developed and perfected and are most successfully used in site investigation in cases of large buildings, airfields, highways, soft ground tunneling and especially in all cases of earthen dams and embankments in all phases.

Geophysical Methods

Geophysical methods are being successfully in mining and oil exploration, their application to assist civil engineering site investigation is only a recent development. Geophysical methods require substantial collection of field data for the interpretation of their results. The fundamental characteristics of the earth are density, rigidity, electrical conductivity, magnetism and elasticity. Variations in the subsurface geological features are always accompanied by variations in one or more of these physical characteristics which can be measured at the surface. Geophysics is the science mainly concerned with the measurement of these variations. It is easy to measure with specially designed instruments but the problem lies in the deduction of the changes in the subsurface geologic conditions responsible for the variations in the physical properties measured. As such careful correlation of the geophysical anamolies with the known geology of the area is essential which is a special skill by itself.

The summary of the most important methods with special reference to site investigation and also applicable to various other engineering problems are given in table I. Of the various methods the ones which can most usefully be applied to site investigation and their limitations are discussed below.

1. *Gravity Methods*:

Variations in subsurface rock densities can be conveniently mapped by making use of such instruments as Pendulum, Gravimeter or Torsion Balance. Pendulum and Gravimeter measure relative gravity and torsion balance measure variations of gravity forces per unit horizontal distances. The gravitational effects of geologic bodies are always proportional to the contrast in density between them and their surroundings. By making very precise measurements of gravity at a series of closely spaced points it is possible to derive significant indications as to the distribution of rocks at depth, as there is generally an increase of density with depth, the uplift of deeper formations will result in thrusting the

TABLE. I.—GEOPHYSICAL METHODS APPLICABLE TO CIVIL ENGINEERING PROBLEMS. AFTER HEILAND.

Geophysical Methods				Field	Geological Applications	Action and Control
I. GRAVITATIONAL	A. TORSION BALANCE			Oil	Anticlinal structures, buried ridges, salt domes, faults, intrusions	Spontaneous Action No depth control
	B. PENDULUM C. GRAVIMETER				Salt domes, burried ridges, major structural trends	
II. MAGNETIC				Oil, Mining	Anticlinal structures, buried ridges, instrusions, faults, iron ores etc.	
III. ELECTRICAL	A. SELF POTENTIAL			Mining	Ores	Reaction to energizing Fields control of depth of penetration
	B. Galvanic Application of Primary Energy	1. potential distribution of secondary field measured	a. Equipotential potential profile	Mining, Oil,	General structural conditions, Bed rock depth on dam sites, ground water, highway problems	
			b. Resistivity c. Point drop ratio	Civil Engg.		
		2. Electromagnetic measurement.	field	Mining	Ore bodies	
	C. Inductive application of primary energy			Oil, Mining	Faults, Folds & Ore bodies	
IV. SEISMIC	A. Refraction			Oil, Civil Engg.	Salt domes, folds, faults, foundation and highway problems.	
	B. Reflection			Oil	Low dip structures, faults buried ridges and deep structures.	

Fig. 13. Gravity Anomalies.

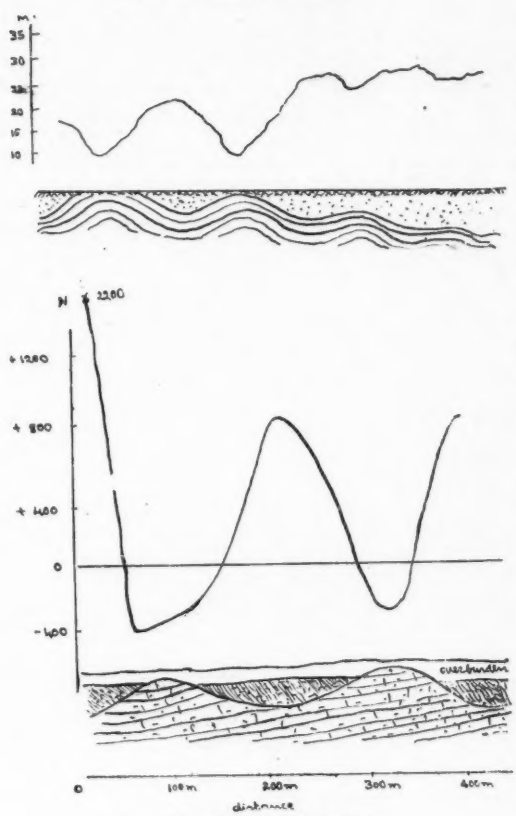


Fig. 14. Magnetic Anomalies.

formation of a higher density in the same horizontal level as lighter and younger geological formations.

The gravity methods have very high resolving power when all possible corrections are made which include planetary effects, effects of elevations, topographic correction and instrumental drift correction. Gravity anamolies are represented by contours called isogams or by profiles in conjunction with geologic sections. (fig. 13) When the data are properly gathered and interpreted these methods are of great value in determining the distribution of rocks underground and their structures. But the method of interpretation is of a trial and error nature and always indirect as such cannot be readily and usefully applied for site investigation in all cases.

2. *Magnetic Methods*:

Magnetic anamolies of rocks are almost entirely dependent of their magnetite content as it is the most widely distributed magnetic mineral in rocks. The magnetic susceptibility of rocks vary much more widely than their densities. The rocks are distinguished as strongly magnetic and weak or non-magnetic. Igneous rocks and their metamorphic representatives as well as iron ores are strongly magnetic whereas sedimentary rocks are generally weak. The magnetic susceptibility of rocks is generally influenced not only by the magnetite content but also by grain size, lightning, heat and contact metamorphism, mechanical stresses, disintegration and concentration and their subsequent alterations during geologic time.

(i) *Magnetometer*:

Measurement of the earth's magnetic field in bore holes, at the surface and from air-crafts reveal valuable information. The distribution of magnetic minerals in rocks is recorded by an instrument called magnetometer. Because of its low expense and speed of application it is well suited for broad reconnaissance surveys immediately after geologic mapping, and to deduce with necessary corrections, the distribution and attitude of geological formations underground, which include the temperature of the instrument, base correction, daily variations, and planetary corrections. Wire fences, bridges, pipelines, tanks, derricks and well casings nearby affect magnetic exploration seriously resulting in erroneous values and thereby wrong interpretations.

The results of magnetic investigations are represented in the form of equal magnetic anamoly called isanomilic lines or in the form of profiles at right angles to the assumed strike. (fig. 14)

(ii) *The Magnetic Air-borne Director*:

This insturment consists essentially of three magnetometer elements, two of which maintain the third in the direction of the earth's resultant magnetic field. This is used for making a rapid regional survey from a low flying aircraft or helicopter. The variations in the intensity of the total or the resultant magnetic field of the earth are traced on a fast moving strip of paper by electronic recording equipment. The detecting unit is towed sufficiently away from the aircraft to avoid the influence of the magnetic field of the flying unit.

The principle of this aeromagnetic method is to record continuously the variations in the value of the total resultant earth's magnetic field from a constant height along a traverse. This is tied in with a continuous photograph (photo strip) of the terrain taken simultaneously from the same aircraft providing easy identification of magnetic anamoly. Detailed ground surveys can then be made over the surface.

Topography and composition of igneous and metamorphic basement rocks as well as igneous intrusives are largely responsible for great variations and the sedimentary rocks for anamolies of lesser magnitude due to variations in their magnetization and structural arrangement. The results are conveniently interpreted sometimes by model experiments. It is often necessary to measure both horizontal and vertical intensities in underground exploration

as magnetic bodies occur both above and below the plane of observation. Depths of magnetized bodies are determined by observing from scaffolds, balloons and in aircrafts. Magnetic methods are useful in determining availability of materials of construction and water supply studies.

Of the four major geophysical methods of exploration the seismic and electrical methods are the most suitable methods in assisting site investigation as in these methods the depth of investigation may be controlled as well as some of the physical properties of geologic bodies can be readily determined, which are definite advantages over the other two methods mentioned above.

3. *Seismic Methods.*

Seismic methods are mainly concerned with the investigation of elastic forces which vary and propagate with time. As depths of investigations can be controlled variations in physical properties with depths, of geological formations may be measured by nothing how certain physical quantities change with horizontal direction.

Elastic wave producing forces are associated with two principal strains.

i compression or dilation, i.e. volume changes, and

ii. shearing stress.

These two strains propogate in a homogeneous or isotropic medium with constant but different velocities. The geological formations are characterised by continuous and discontinuous variations in their physical properties and for practical purposes each geologic formattion is assumed to be a perfect elastic body in which the stress is proportional to the strain and in which there is no elastic hysteresis. As such application of seismic methods largely depend on the contrast in elastic properties of geologic bodies and the surrounding media, and the differences in the velocity of elastic waves in different geological formations are the criteria for the interpretation of results of seismic exploration. The velocity of elastic waves is highly influenced by certain combinations of Young's modulus of elasticity, Poission's ratio and density. The seismic phenomena are comparable to optical phenomena. The principle of seismic exploration therefore is to determine the distance between the earth's surface and one or more of reflecting or refracting surfaces in the underground. The wave propagation is always characterised by velocity, frequency, intensity, direction, travel-time, wave length, absorption, reflection and refraction.

The important techniques of seismic explorations are

1. Reflection method, and
2. Refraction method

The first method is based on the reflection of elastic waves at subsurface discontinuities and is extremely useful in the exploration of deep formation boundaries over 20,000 ft. But it is not suitable for shallow depth investigations.

The refraction method based on the refraction of elastic waves at physical discontinuities in the ground is readily applicable to civil engineering site investigations.

(*i*) *The Refraction Method* :

A sudden elastic disturbance is set up by exploding a charge of dynamite at or near the surface and the elastic impulses transmitted through the ground are picked up by vibration detectors such as seismimeters, geophones, pickups etc. located at the ground surface farther away from the charge. The detectors transform the elastic impulses into electrical impulses which are transmitted to a recording apparatus where they are amplified and recorded on a fast moving (2 ft./Sec.) strip of photo sensitive paper. (Fig. 15). The instant of time of explosion and the

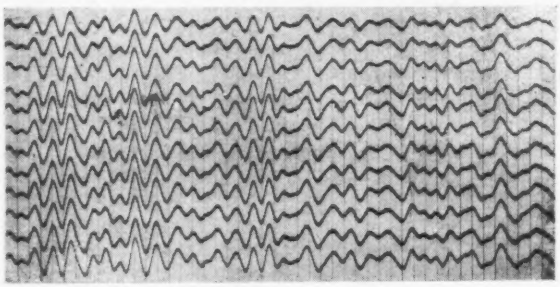


Fig. 15. A Typical Seismogram—graphic record of elastic Impulses.

arrival of the first vibration impulse at each detector are also recorded and the 'travel-time' i.e.' the time elapsed between the generation and reception of elastic impulses is measured. The time distance curves are drawn which give information on the paths of seismic waves below the ground, their refraction and depths of refracting surfaces. The recordings are made over a net work of points spaced a few hundred feet to a mile apart on the surface and the numerical values under the guidance of competent geologists are contoured to show the attitude of the strata at depth.

(*ii*) *The Seismic Equipment* :

Seismic equipment for site investigation consists of three to twelve seismometers (vibration detectors) an amplifier unit operated by a battery accumulator, consisting of twelve independent amplifiers one for each detector and a thirteen channel oscillograph and an exploder.

(*iii*) *Field Operation* :

A hole about 4 to 6 ft. deep called the shot-hole is bored in the ground at the site and about $\frac{1}{4}$ to a pound of dynamite depending upon the sensitivity of the seismic equipment (and also to prevent the shattering of the ground surface by explosion) is placed in it. The seismometers are laid-out in small

Fig. 16. The Explosion.

tight-fit holes in the ground for a better contact in a straight line (profile shooting) or an arc round (fan shooting) the shot point. The spacing of the detectors and the shot-hole depends upon the depth to be explored and the details required. The area over which the seismic exploration is made from a given shot point is called 'Seismic spread'. Generally, in civil engineering site investigations a spread of 5 to 8 times the depth is required. The detectors are connected by long cables to the recording apparatus. Radio or telephone contacts are maintained between the person in charge of the recording equipment and the person responsible for placing and firing the explosives. (Fig. 16).

(v) *Interpretation* :

When a charge is detonated at the shot point (fig. 17) elastic waves with a spherical wave front travel outwards. Let us assume for purposes of illustration a two layer structure, a bed rock formation and a thick overburden, and the velocities of seismic impulses to be 5,000 ft. per Sec. in the bed rock and 2,000 ft. per Sec. in the overburden. When the wave front reaches the surface of the rock it advances at a velocity of 5,000 ft. per Sec. As it advances in all directions in the rock it starts a new series of waves, according to Huygen's principles, which travel from the surface of the rock back to the ground surface through the overburden again at a velocity of 2,000 ft. per second (also from a certain distance the waves that have taken a detour through the rock medium arrive ahead of the waves through the upper low speed medium). The envelop of these new waves towards the ground surface is the refracted wave front. Therefore it is evident that the first waves to arrive at the detectors close to the shot point are those which have travelled directly through the overburden. Also the waves

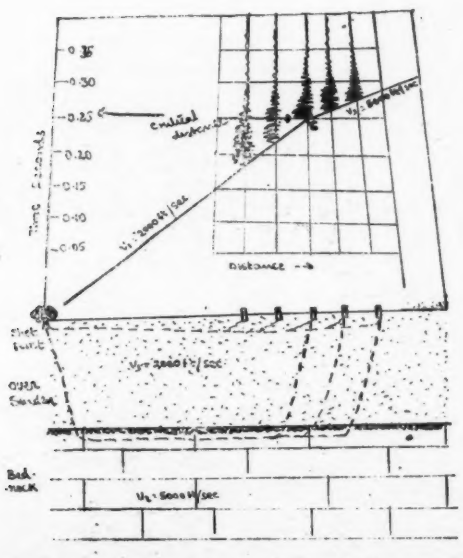


Fig. 17. Transmission and Recording of Seismic Impulses.

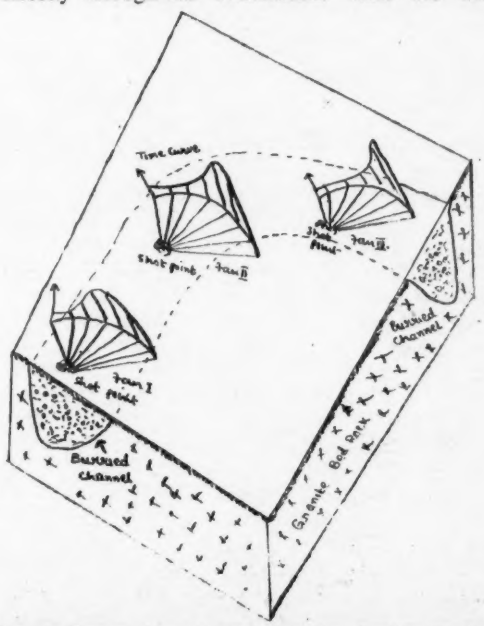


Fig. 18. Tracing a buried channel by fan-shooting technique.

which are refracted from the rock surface arrive simultaneously and this simultaneous arrival of the two waves is indicated by a break in the travel-time curve which is the critical point. At distances farther away from the critical distance from the shot point the first arrival always is the refracted wavefront. If the time elapsed between the explosion and the reception of impulses recorded and plotted graphically a time/distance graph consisting of two straight lines intersecting at the critical distance is obtained, and the slope of the first part of th graph corresponds to the wave velocity through the upper low speed medium overburden and the slope of the second part to the velocity through the high speed medium bed rock.

From these two velocities and the abscissa of the break in the time/distance graph the depth to bed rock is calculated from the expression

$$d = \frac{x}{2}\sqrt{\frac{v_2 - v_1}{v_2 + v_1}}$$

Where v_1 denotes the velocity of transmission through the overburden,

v_2 denotes the velocity of transmission through the bedrock,

x the critical distance, and

d depth to bed rock.

(*iv*) *Illustration* :

Tracing a burried channel in a dam site.

Burried gorges or valleys, although they are revealed by trial borings the tracing of their course forms a major problem. Burried channels introduce complications in securing adequate cut off to guard against percolation under dams. However, it is possible to trace their course easily by seismic refraction by making use of the fan shooting technique.

The shot point is located at a point where the buried channel has been detected previously. The charge is detonated and the travel time is recorded. The greatest time travel will be recorded at the detector which is directly on the channel. This station is made the shot point for the next seismometer arc and by proceeding this way the course of the channel is traced. (Fig. 18).

The most important requirement for the refraction method is that the ground must be composed of two or more formations in which the seismic impulses are propagated at a higher velocity always through the lower formations and therefore this method is ideally suited to determine the hard rock line, which is an essential requirement for civil engineering undertakings.

4. *Electrical Methods*

Electrical methods have been applied with great success to determine the depth to bed rock on dam and tunnel sites, harbour investigations, location of water bearing formations and construction materials for highways, rail road and dams as well as burried objects like pipe line.

Geologic structures can be mapped by their reactions to electrical and electromagnetic fields. There are two methods of electrical exploration.

(i) Potential methods, and (ii) Electromagnetic methods.

(*i*) *Potential methods* :

The potential methods are divided into :

a. Self-potential method

In this method the electrical field is furnished by the electro-chemical polarization of geologic formations. Electro-filteration potentials are produced by the movement of water in porous formations which indicate the porosity of beds.

b. Equi-potential method

In this method the potential distribution between primary electrodes is observed by measuring equipotential lines. The potential differences help determination of geologic bodies and structures.

c. Electrical Resistivity methods

In these methods the apparent resistivity of geological formations which is a function of depth penetration therefore a function of spacing of electrodes, is measured by the ratio of voltage and current multiplied by a spacing factor. By these methods it is possible to determine the hard rock line ground water and geologic structures.

d. Potential drop-ratio method

This method is based on a comparison of voltage difference with reference to magnitude and phase in successive ground intervals and is useful in the determination of depth of horizontal and vertical formation boundaries.

e. Electrical transient (Electran) method

This method involves in the use of transients for surface potential measurements with similar electrode arrangement as that of a electrical resistivity method. The time change of the potential between two electrodes is measured.

(*ii*) *Electromagnetic methods* :

The electromagnetic methods fall into two groups *a.* Galvanic methods and *b.* Inductive methods.

In galvanic methods current is supplied by grounded electrodes and in inductive methods current is induced to flow in subsurface conductors. The interpretation of the results is merely a qualitative nature and therefore is concerned only with locating areas of anamolous indications and depth determinations are generally not possible.

Of these various methods the electrical resistivity methods are most usefully and successfully applied for civil engineering site investigation.

(*iii*) *Electrical Resistivity Methods* :

The electrical resistivity of a rock is defined as the resistance offered by a unit cube of the rock to the flow of electric current normal to one of its faces, and it depends upon the amount and salinity of the moisture or the pore water it contains. The The more porous or the jointed and fissured the rock is the lower is its resistivity. Thus in general igneous and metamorphic rocks offer greater resist-

ance than sedimentary rocks.

The electrical resistivity methods utilize the fact that the electrical resistivity of the loose, incoherent or soft and porous geological formations such as alluvium, drift, sand and clay is different from that of the bed rock over which they are usually deposited. The success of the methods depends upon the amount of variation in the resistivity of the overburden and the bedrock of a particular area.

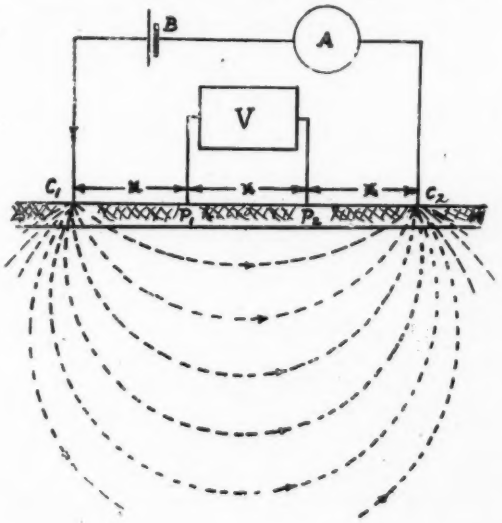
(*iv*) *Equipment* :

The resistivity equipment consists essentially of

1. a generator or a high voltage battery as a source of current.
2. a portable voltmeter or potentiometer for measuring small potential differences accurately.
3. a portable multi-range milliammeter for measuring currents.
4. four iron or other metallic spikes for electrodes.
5. abundant well insulated wire, and
6. devices for elemination of effects due to polarization at the electrodes and due to small currents in the ground.

(*v*) *Procedure* :

To measure the resistivity of the ground an electric current is introduced into the ground through two metal spikes called current electrodes which are connected by insulated wires through a milliammeter to a generator. The current flows through the ground as shown in the figure. (Fig. 19). Theoretically the



LINES OF CURRENT FLOW.

Fig. 19.

current flow extends to infinite depths, but the intensity diminishes rapidly with depth, and for practical purposes the current can be considered to be confined within a depth equal to approximately one third of the distance between the current electrodes.

In a homogeneous ground the lines of flow have a definite shape independent of the medium or the distances between the electrodes. As such the current penetration can be varied by varying the electrode spacing.

Next, another pair of electrodes called potential electrodes are placed between the current electrodes in a straight line at equal distances. These are connected to a potentiometer and the voltage drop V between the potential electrodes resulting from a current C applied between the current electrodes is measured, and the resistivity of the ground r is proportional to V divided by C multiplied by the electrode spacing.

The value of r so measured is only apparent resistivity of the ground, as the ground is rarely homogeneous.

The depth penetration is controlled either by electrode spacing or position of the electrode system as a whole and the underground distribution of rocks is deduced by the variations in the apparent resistivity obtained as a function of depth.

Thus there are two methods of resistivity determination.

1. Expanding electrode separation technique, and
2. Lateral traversing technique

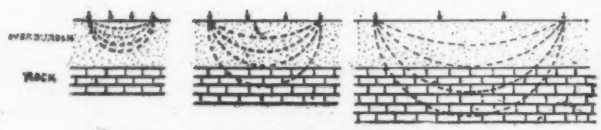
Expanding Electrode Separation Technique or Wenner-Gish-Rooney Method (using a set of high voltage batteries as a source of current) or Megger Method (using a hand cranked generator).

As the depth of peneration of the current into the ground can be controlled by the electrode spacing by increasing the distance between the electrodes about a fixed central point the depth of current penetration is increased. In the W-G-R method the two potential electrodes are placed on a line in between the two current electrodes in such a way that all the four electrodes are at equal distance from one another, when the expression for the resistance is

$$r = 2\pi \times \frac{V}{C}$$

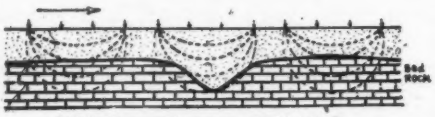
Where r is the resistance, V—voltage drop, C—current supplied between the electrodes and 'x' the distance between the electrodes. If the ground is homogeneous the resistivity is constant for all electrode spacings and equal to the actual resistivity of the geological formation. Therefore the graph of resistivity against electrode spacing would be a constant.

Let us consider a case of a ground condition wherein there is a homogeneous overburden of alluvium concealing a homogeneous bed rock of



EXPANDING ELECTRODE TECHNIQUE.

Fig. 20.



LATERAL TRAVERSING TECHNIQUE.

Fig. 21.

greater resistance extending to great depths. When the electrode separation is small compared to the thickness of the overburden practically all current flow will be through the overburden. As the electrode spacing is increased the depth of current penetration increases (fig. 20) and therefore the resistivity also increases due to the presence of the bed rock of higher resistivity. Then when the electrode separation is further compared with the thickness of the overburden most of the current will pass through the bed rock and the measured resistivity will then approach the true resistivity of the bed rock.

Thus by a series of measurements made at increasing electrode spacing a resistivity curve is obtained by plotting the values of resistivity as ordinates and corresponding values of electrode spacing as abscissas. An upward trend of the curve indicates increase in resistivity with depth and suggests the presence of rock, gravel or other high resistance materials, while a flat or a descending curve is indicative of silt and clay. An abrupt change in the curvature indicates a change in material at a depth approximately equal to the electrode spacing at which the change occurs. Also the thiner the overburden the steeper would be the curve and vice versa. The resistivity curve is then superimposed on a series of standard theoretical curves computed for various values of depth and resistivity ratio and the depth is determined from the theoretical curve which closely corresponds to the field curve.

(*vi*) *Lateral Traversing Technique*

In this technique the whole electrode system is moved along a traverse while the electrode spacing is kept constant i.e. the depth penetration is kept constant, and the horizontal variation or variation in depth of a given geological formation is determined. The apparent resistivity is measured at successive stations along the line of traverse (fig. 21) and is plotted as ordinates against distance to obtain a resistivity profile.

Since the effective depth penetration is controlled by electrode spacing, a convenient spacing is chosen which is slightly greater than the maximum depth to be explored. If the subsurface conditions are uniform within a depth approximately equal to the electrode spacing the resulting curve obtained by traverse in the ground with a constant electrode spacing will be a straight line. Any lateral variation in the subsurface geology is indicated by anomalies on the resistivity profile.

The electrical resistivity methods are very useful therefore in Civil Engineering site investigation in conjunction with auger holes, trial pits, drifts and bore holes. They are commonly applicable in determining

1. depth to bed rock i.e., thickness of overburden
2. certain characteristics of rock formations like attitude, discontinuity, unconformity, etc.
3. location of construction materials

In addition by other related techniques like using five electrode configuration the inclination of the strata as well as vertical features such as dikes, faults etc., can be traced.

Lateral variations in either the homogeneity or thickness of any geological formation within the effective range of current penetration will cause variations in the apparent resistivity measured by any of the above two methods at the surface.

Careful correlation of the resistivity measurements with the known geology of the site concerned in conjunction with check borings, is essential as these methods indicate an average estimation of the variations.

CONCLUSION

Foundation conditions are essentially geological conditions. Exhaustion of good sites, and the necessity to build wherever required regardless of geologic complexity of the site accentuate the demand for adequate interpretation of the geological conditions. Design and construction engineers plan their projects on the data available from geological investigation and interpretation of the site conditions. To construct a thorough three dimensional picture of subsurface foundation conditions of a site the geological investigations are supplemented at present by modern methods. A knowledge of the possible geological conditions based on a preliminary geological survey is essential in order to select the most suitable method for specific needs. Some of the most important, suitable and well established modern methods, their principles and limitations in applying for site investigation have been discussed. The application of these dramatically expanding techniques for engineering site investigation is a very recent development.

They have been successfully used in major civil engineering undertakings in all parts of the world under varied ground conditions in conjunction with geological investigations. Although these methods

[*Continued on page 29*

Costing for Tariff Purposes in Electrcity Supply

By B. K. BANERJEE

An unit of electricity is homogenecus but it is well-known that its use is diverse. The cost of supply varies with this diversity and therefore, in electricity supply industry, the average cost of whole supply cannot be charged to every type of consumer i.e. domestic, commercial or industrial etc.

Consideration has also to be given to Section 49 of the Electricity (Supply) Act, 1948, under which the Electricity Boards, in fixing tariff, cannot show any undue preference to any person. For private licensees, Section 23 of the Indian Electricity Act, 1910 applies. In the corresponding British Act (Section 37 of the Electricity Act, 1947) it has been stipulated that the Board shall not show any undue preference to any person or class of persons. It would appear, therefore, that the requirements under the British Act are more stringent in that no undue preference could be shown to any class of persons. It is clear, therefore, that the industry must have knowledge of the cost of supplying electricity to any person. In fact one of the main principles of tariff-making should be to ensure that the charges reflect the costs of supply. It becomes often necessary to determine the cost of giving supply to a large industrial consumer when detailed costing becomes absolutely essential. There are many difficulties in estimating cost of supply to a class of consumers or a consumer who make varying requirements upon the system.

It is now necessary to consider fundamental economics of the supply. The special features are that electricity has to be supplied when demanded and that it cannot be stored to meet peak demands. It is produced for instantaneous use and unlike gas or coal, it cannot be stored on a large scale. This means that the supply authority has to be ready with adequate generating plant, transmission and distribution system of sufficient capacity for supplying any demand of power on any time of the day. Most industrial consumers make their demand between 8 A.M. to 5 P.M. On the other hand most domestic consumers make their demand between 5 P.M. to 10 P.M. Other types of consumers have varied load characteristics. Therefore, the shape of load curve presents a major problem i.e. how to charge consumer according to the demand they make on the system. It is obvious, however, that if the tariff is made simpler and more standardised, there will be greater degree of averaging i.e. the divergence between the cost of supplying a consumer and the charge made to that consumer will increase.

Economics of Electricity Supply

The annual capital charges on the generating plant, transmission and distribution system have to be met even when they are used at full capacity for a short period only. One of the particular characteristics of this industry is that the capital charges are disproportionate in relation to the total cost of production. The logical outcome of the highly capitalised nature of the industry is to resolve the costs into two components (i) demand or fixed charges (ii) unit or running charges. This simple two-part allocation could easily be assessed in the early days of compact low voltage systems and a regular determinate peak period. Now-a-days, due to the complex interconnected systems and the extensive and varied use in the home, factory and elsewhere, the estimate of these two components presents a complicated task.

In any electricity system the whole process can be divided into two parts—generation and distribution. The generation cost can be broken down to demand and running components as at that stage the unit is completely homogeneous and its diverse use does not arise until it reaches the consumers' premises. The determination of cost of production electricity at generating stations and the allocation to cost of production have been provided in the Eighth and Ninth Schedules to the Electricity (Supply) Act, 1948 and it is not proposed to deal with the same in details here. In addition to generating electricity, some Boards and organisations purchase electricity in bulk and in almost all the cases, tariff applicable to such purchases is on a two-part basis i.e. it has a demand component and an energy component.

Apportionment of Costs

It is now necessary to assess the distribution cost. Under modern practice of tariff-making, trinomial apportionment of costs is made as follows :

(1) Demand related i.e. the component of the standing cost which is directly proportionate to the maximum demand.

(2) Unit related.
(3) Consumer related i.e. the component of standing cost which is independent of electricity actually supplied but is proportionate to the number of consumers.

The demand costs can be sub-divided into the following :

(1) System capacity cost i.e. the demand charges of the bulk supply tariff or the fixed component cost of generation as determined under the Ninth Schedule to the Electricity (Supply) Act, 1948.
(2) Regional capacity cost i.e. EHV and HV system for transmission from the bulk supply point or generating station to the main transforming points.
(3) Local capacity costs i.e. MV and LV distribution system.
(4) Individual capacity cost i.e. those arising from the provision to meet demand requirement of individual consumer.

Although No. 4 has been included in capacity cost, it is more directly related with consumer costs.

Statistical Data Required

It is now proposed to consider the statistical and other data essential for the purpose of consumer class costing. The following classes of consumers can be taken into consideration :—

(a) HV industrial consumers
(b) LV industrial consumers
(c) Domestic consumers
(d) Commercial consumers.

For each of the above classes, the following data are required :—

(*i*) Demand
(*ii*) Unit sold
(*iii*) Number of consumers.

There is no difficulty in obtaining information required under (ii) and (iii) ; but it becomes a problem assessing the demand to be used under (i). In most of electricity undertakings, the annual maximum demand is usually established in the evening of the summer months. The demand has to be allocated to the consumer classes according to their responsibility in the creation of this collective maximum demand. There are many ways of apportionment of demand costs amongst the various classes of consumers. These are as under :—

(1) Peak responsibility—contribution of various classes of consumers to the actual maximum demand.
(2) Potential peak period—contribution of various classes of consumers to the demand during potential peak periods.
(3) Maximum demand—maximum demand of each class of consumer irrespective of time and occurence.
(4) Consumption and demand method—a combination of annual consumption, annual maximum demand and consumers maximum demand.

Determination of demand

The peak responsibility method is considered to be the most suitable one in our system as in almost all cases, the peak occurs in the evening. In future when the tendency of the system load curves will be to develop peaks at two or three different times of the day, the potential peak period method will be better suited to solve the problem. Which are the potential peak periods ? These are assumed to be all half hours during the year when the demand was 95% or more of the actual recorded maximum demand. In order to even out the effects of extreme summer conditions, the potential peak period over three consecutive years may be taken into account.

After determining the peak period, the next problem, which is most difficult, is to analyse the load curve for finding out the load shared by various classes of consumers during that period. Some countries have developed a statistical technique known as "Multiple Regression Analysis" to analyse the system load curve. The method can briefly be described as follows :—

If the values of a variable (e.g. an individual household's annual consumption for cooking purposes) depend on the accompanying values of two or more associated variables (e.g. number of adults, number of children etc.) and a sufficient number of sets of observed values are available, the effect of each of the associated variable can be separated out by Multiple Regression Analysis, on the assumption of linear (i.e. straight line) association. The resulting estimation equation may take the form of

$$Y=a+b_1x_1+b_2x_2+ \ldots \ldots \ldots$$

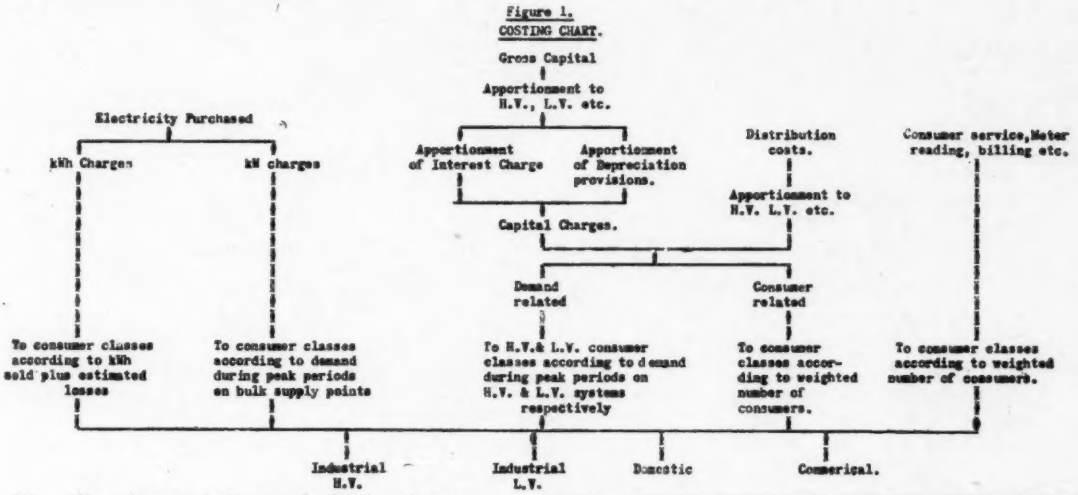
For the three variables adduced as example, it would be $Y=a+b_1x_1+b_2x_2$ in which 'Y' denotes the estimate on annual consumption for cooking purposes, 'a' a constant, 'b_1' and 'b_2' Partial Regression Co-efficients, 'x_1' the number of adults in a household and 'x_2' the number of children in a household. In a similar way, if the annual consumption of the different classes of consumers viz. domestic, commercial, industrial etc. together with the system maximum demand are known for a sufficient number of system, a similar equation can be derived.

After assessment of the loads shared by different classes of consumers at the peak periods, costing demand is found out. It has already been mentioned that units sold and the number of consumers for each class are easily available. However, for costing purposes distribution losses are taken into account and this is done by assuming a loss multiplier. The number of consumers are also weighted to allow for disparities in the cost incurred in respect of the average consumer in the various classes.

Detailed Application of the Method

In Fig. 1, a costing chart is given. The sequence of the application of the method follows the general line of approach illustrated in the chart.

Figure 1.
COSTING CHART.


Gross Capital
Apportionment to H.V., L.V. etc.
Electricity Purchased
kWh Charges
kW charges
Apportionment of Interest Charge
Apportionment of Depreciation provisions.
Distribution costs.
Consumer service, Meter reading, billing etc.
Apportionment to H.V. L.V. etc.
Capital Charges.
Demand related
Consumer related
To consumer classes according to kWh sold plus estimated losses
To consumer classes according to demand during peak periods on bulk supply points
To H.V. & L.V. consumer classes according to demand during peak periods on H.V. & L.V. systems respectively
To consumer classes according to weighted number of consumers.
To consumer classes according to weighted number of consumers.
Industrial H.V.
Industrial L.V.
Domestic
Commerical.

(1) *Allocation of bulk supply kWh—charges.*

In the Table 1 of statistical data, consumers have been sub-divided into classes. The kWh charges has been allocated according to the sales to the individual classes and the estimated losses in distribution.

(2) *Allocation of bulk supply kW—charges.*

In the Table 1, the demands by the various classes of consumers at the time of system peak demand have been shown. These figures can be obtained by the statistical method described earlier. Strictly speaking, the demands should be converted to KVA by means of estimated power factors but for simplification in calculations, kW figures have been taken.

(3) *Capital expenditure.*

Table 2 shows the capital expenditure under the various heads.

TABLE I.—STATISTICAL DATA

Units	*H.V. Industrial*	*L.V. Industrial*	*Domestic*	*Commercial*	*Total*
Units sold (thousand)	9000	2900	3400	1700	17000
Loss Multiplier	1.1	1.15	1.2	1.2	1.13
Units purchased (thousands)	9900	3300	4100	2000	19300
Demands.					
Costing Demand System (kW)	500	500	3000	1000	5000
Regional (kW)	500	500	3000	1000	5000
Local (kW)	—	500	3000	1000	4500
Consumers.					
Number	30	300	12000	6000	18330
Weight Factors					
(a) Individual Capacity Cost		2	1	1	
Equivalent consumers		600	12000	6000	18600
(b) other consumer costs.	20	4	1	1	
Equivalent consumers	600	1200	12000	6000	19800

TABLE—2. CAPITAL EXPENDITURE

	Lakhs. Rs. nP.
High Voltage—(a) System (sub-station & mains)	40.00
(b) H. V. consumers	15.00
Low Voltage — System (sub-stations & Mains)	20.00
Services	30.00
Meters.	8.00
Office buildings, furniture, etc.	12.00
	125.00

(4) *Capital charges.*

The interest and depreciation charges are apportioned pro-rata in capital items given in Table 2. They are shown in Table 3 under Cost Data.

(5) *Apportionment of capital charges and distribution cost.*

In Table 3, the capital charges and distribution costs are jointly apportioned according to their assumed relationships to the demand on systems and to given classes of consumers and to the number of consumers served. The H. V. system costs are regarded as wholly demand-related. Those in respect of services, meters, tools, offices etc. are treated as wholly consumer-related. The general establishment charges are distributed pro-rata amongst the other costs.

The cost per unit, cost per kW and cost per consumer are calculated from the cost-data and statistical-data. The segregated demand-related, consumer-related and unit-related costs are then allocated to the consumers classes as given in Table 4. The calculations are made from the statistical data of Table 1 and cost data derived from Table 3.

The total costs allocated to the different classes of consumers i.e. H.V. industrial, L.V. industrial, domestic and commercial can be utilised in framing suitable tariffs. While fixing up demand and energy blocks in the case of 2-part tariff for H.V. industrial consumers depends upon a number of factors, the average cost per unit sold at the working load factor

TABLE 3.—COST-DATA (IN RS. -LAKHS).

Item of expenditure	Total	Consumption costs	Demand-related or capacity costs			Individual Capacity		Consumer cost	Establishment or Residure cost
			System	Regional	Local	H.V.	L.V.		
Purchase of electricity.									
(a) KWH (unit) Charges	5.8	5.8							
(b) KW (Demand) Charges	3.6		3.6						
Total	9.4								
Transmissin & Distribution.									
(a) H.V. System	2.0			2.0					
(b) H.V. consumer	0.5					0.5			
(c) L.V. System	2.0				2.0				
(d) L.V. consumer	1.5						1.5		
Total	6.0								
Consumer service, meter reading, billing	2.0							2.0	
General establishment charges	1.5								1.5
Interest	5.5			1.8	0.9	0.7	0.8	1.3	
Depreciation	2.7			0.9	0.5	0.4	0.4	0.5	
Total	27.1	5.8	3.6	4.7	3.4	1.6	2.7	3.8	1.5
Total adjusted to cover establishment costs 5.9%	27.1	6.1	3.8	5.0	3.6	1.7	2.9	4.0	
Derivation of cost formula.									
(a) Divisors	--	19300 thousands unit	5000 kW	5000 kW	4500 kW	30 (A)	18600 (W)	19300 (W)	
(c) Cost per unit		3.16 nP.							
(c) Cost per kW			Rs. 76	Rs. 100	Rs. 80				
(d) Cost per consumer						Rs. 5660	Rs. 15.6	Rs. 20.2	

N.B. (A) denotes Actual consumers.
(W) denotes Weighted consumers.

of the consumers can serve as a starting point on which the tariff calculated should bring forth desirable revenue return. It is seen from the average cost per unit sold as given in Table 4 that the same comes to 6.5 nP per unit for H.V. industrial consumer and 9.2 nP per unit for L.V. industrial consumers. For domestic and commercial consumers, the average cost comes to 38.6 nP and 31.3 nP per unit respectively. It has already been said before that the peak in most of our systems occurs during the evening time and as such it is reasonable that domestic and commercial consumers should be charged at a comparatively higher rates than industrial consumers. In fact, in most of the electricity supply undertakings the tariffs actually charged are related in a similar manner. With the increase in the industrialisation, there is already a tendency towards creation of a day peak almost equal to the night peak.

TABLE 4.

Class of consumers	*Statistical data*	*Cost data*	*Cost Rs. lakhs.*
H.V. Industrial Consumers	9000 thousand units	$3.16 \times 1.1 = 3.5$ nP. per unit	3.12
	500 kW	$76 + 100 =$ Rs. 176 per kW	0.88
	30 consumers	$5560 + 20 \times$ Rs. $20 =$ Rs. 6054 per consumer	1.82
			5.82 i.e. 6.5 nP. per unit.
L.V. Industrial Consumers	2900 thousand units	$3.16 \times 1.15 = 3.65$ nP. per unit	1.06
	500 kW	$76 + 100 + 80 =$ Rs. 256 per kW	1.26
	300 consumers	$2 \times$ Rs. $15.6 = 4 \times$ Rs. $20.2 =$ Rs. 112 per consumer	0.33
			2.67 i.e. 9.2 nP. per unit.
Domestic Consumer	3400 thousand units	$3.16 \times 1.2 = 3.8$ nP. per unit	1.29
	3000 kW	$76 + 100 + 80 =$ Rs. 256 per kW	7.68
	12000 consumers	$15.6 + 20.2 =$ Rs. 35.8 per consumer	4.30
			13.27 i.e. 38.6 nP. per unit.
Commercial Consumers	1700 thousand units	$3.16 \times 1.2 = 3.8$ nP. per unit	0.64
	1000 kW	$76 + 100 + 80 =$ Rs. 256 per kW	2.56
	6000 consumers	$15.6 + 20.2 =$ Rs. 35.8 per consumer	2.15
			5.35 i.e. 31.3 nP. per unit.
		Total	Rs. 27.11

In such cases the potential peak period method can profitably be utilised in the apportionment of demand cost among the various classes of consumers. When in future, the day peak will equal or be more than the night peak, the tariff pattern should automatically change to suit the altered conditions. Then the difference between tariffs offered to domestic and commercial consumers and the industrial consumers should tend to grow narrower and narrower.

Conclusion

It will be seen that the results obtained by using the above method of cost allocation depend to a large extent on the class-load curve estimate made on the proportion between demand-related and consumer-related costs and the various weighting factors used. Further investigations are required to enable us to utilise this method with profit. It is apparent that although the above method cannot provide ready-made tariffs, it no doubt indicates how the tariffs offered to consumers are related to costs of giving supply.

It must be recognised that some costs will have to be allocated arbitrarily based on utilisation research, but such research should not be carried beyond certain limit after which it becomes too much expensive. There should be research into the electrical characteristics of all types of consumers otherwise some of the methods of charge will continue to apply because of some personal preference for them. Some people still think that tariff-making is an art and not a science. This attitude is more of a justification of arbitrariness. Systematic research should immediately be started on the following lines:—

(a) The requirements and characteristics of the different classes and types of consumers.

(b) The nature of the demand on the supply system made by different classes of consumers and and by electrical appliances and apparatus.

(c) The means of improving system utilisation with a view to reducing production and distribution costs.

(d) The study of factors affecting the cost of supplying the various classes of consumers and the types of load.

(e) Comparison with non-electric media for supplying consumers' requirements.

In India, the electricity supply industry is in the hands of both public and private sectors. While the accounts of the private electricity supply companies are required to be prepared in accordance with the accounting forms specific under the Indian Electricity Rules '56, no such standardised forms are required to be followed by the State Electricity Board working in the public sector. It is seen that the various Boards have adopted different forms of accounting and that too varies widely with the forms specified under the Indian Electricity Rules, 1956 and followed by the private electricity supply companies. While accounts of the private companies reveal quite a number of useful costing data, the accounting forms adopted by the Boards hardly contain useful figures which could be utilised in cost research and utilisation research. It is suggested that a uniform method of keeping accounts is evolved for the Electricity Boards. Unless this is done, no useful attempt could be made in the field of cost analysis which is very essential for any commercially-run organisation.

[*Continued from page 24*

Modern Methods of Site Investigation and their Limitations

indicate an average estimation of the ground conditions and their subsurface expressions when their results are properly interpreted and correlated with the known geology of the area more weighted results can be arrived at.

There is a greater emphasis among engineers and contractors that foundation data are essential prerequisite to efficient substructure design. Co-operation between engineers and geologists to foster exchange and extension of knowledge and understanding and research to improve and extend the application of these techniques will help to solve a variety of problems of foundation engineering, as these techniques have already become more dynamic and indispensible.

ACKNOWLEDGMENTS TO

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(3) Lit. Dept, Veb Carl Zeiss Jena, German Democratic Republic (for the photo copies of photogrammetric instruments.

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Seventh Irrigation & Power Seminar
A Report

His Highness Maharaja Shri Jaya Chamaraja Wadiyar Bahadur, Governor of Mysore inaugurated the Seventh Seminar of Power and Irrigation at Bangalore. It was held in the Banquetting Hall of the Vidhanasouda from September 10 to 12. Hafiz Mohammad Ibrahim, Union Minister for Irrigation & Power was the Chairman.

The subjects discussed during the Seminar were as follows :

(1) Apportionment of costs and allotment of Reservoir Storage spaces for Hydel Power, Irrigation, Navigation and Flood Control Schemes in Multipurpose Projects.

(2) Establishment of Supergrids and Organisational procedure for their control.

(3) Realisation of the procedure for disposal of surplus Machinery on Projects including Revision of Formula for calculating Depreciation of Machinery.

As Hafiz Mohammad Ibrahim was busy in another programme, the discussion on the establishment of Supergrids and Organisational procedure for their control was held under the Chairmanship of Dy. Minister Shri Jaisukhlal Hathi. The Chairman asked Mr. Nair, Member (Hydro-electric) CW & PC to introduce this subject "Establishment of Super-grids and organisational procedure for their control". Mr. Nair in introducing the subject stated as follows :

Consequent on the rapid pace of industrialisation set by the successive Five Year Plans, the Power development programme in the country has assumed sizeable dimensions. Side by side with the planning and development of large hydro and thermal power stations and associated transmission systems in the various States, it is important that a co-ordinated plan is evolved for establishing regional Super-grid systems by inter-connecting the various State Grids so as to ensure the maximum utilisation of the benefits of electric power supply over vast areas of the country and also derive the maximum benefit out of the available hydro and fuel resources. It is in this context that the various steps involved in the planning, design and operation of super-grid systems have to be considered. Based on the anticipated growth and pattern of load demands in the various regions and the existing and potential power resources, the relative economics of the various alternatives of interconnecting the State Grids have to be evaluated and a Master Plan evolved for the region as a whole. Some priorities have to be laid down for putting up the various inter-State links (or Supergrid systems) so that the respective States may plan the development of their State Grids so as to fit within the broad frame-work of the Master Plan for the region as a whole and phase the construction of the various lines accordingly. It is necessary that a suitable method is also evolved for financing the inter-State links and the apportionment of costs between the concerned States. Likewise, the organisational set up for the planning, design, construction, operation and maintenance of the Supergrid system and the broad principles upon which the inter-State tariffs should be based also require careful consideration.

Altogether there were nine papers including papers from Shri Hayath Chairman of the Central Water & Power Commission. All the authors were more or less unanimous to the need for establishment supergrids in the country. A number of points which deserve consideration by the members have been brought out in these papers. The authors have also brought out the necessity of establishment of state grids, regional grids and national power grids. The particular economic advantages of super-grids have been brought out more clearly by Shri Hayath and Swayambu, Shri Bhatia, Shri Sarkar, Sri Minocha, Shri Nageswar Rao, Shri Pappu.

The advisability of establishing super-grids is as follows: It is well known that interconnection of power grids leads to a considerable economy in capital cost. The broad lines on which the super-grids have to be evolved are: There is more or less unanimity among the authors of the various papers on the necessity for the foundation of super-grids. The various advantages are: (1) diminity in daily load curves and annual load curves (2) water periods may be different (3) Hydro power for thermal combination (4) There is reduction in the standing hydro-electric and thermal plants. So there was almost complete agreement on the need for long term planning in the various regions iirrespective of political considerations, of the need of establishing the various stations on purely economic considerations. It was emphasized that based on the long term load survey, assessment of power potential, both hydro and thermal resources should be made and a fairly economical and large size plants should be planned and installed and also interconnection between the various State systems should be made. It was suggested that while evolving this, establishment of large central generating stations, owned by the grid of the State Electricity Board or by an independent authority, should be considered. Continuous assessment of the

requirements of power should be made on a regional basis, and plans evolved for setting up generating stations according to the utmost economy in capital cost and also in operating cost. Two or three papers gave examples of the advantages of economical operation. There was an excellent example based on experience, gained during the last two years. It was of Hirakud hydro-station and Rourkela thermal station. It was claimed that it was possible to effect the increase in free firm capacity by 10% by combined operation and also increase the energy generation by 30%. Similarly, Shri Sarkar in his paper said that the combined operation of West Bengal, Bihar and Orissa may result in considerable economy. He has mentioned that the shortage of about 900 MW in this region may be brought down to about 500 MW of West Bengal, Bihar and Orissa in this way. The value of the additional capacity is estimated at about Rs. 50 crores in capital cost, thus effecting a saving of about 10.8. crores in operational expenses. Similarly, in another paper by Shri Harbans Singh, it has been stated that by interconnection of the Punjab and U. P. States, considerable economy can be effected in various factors.

Coming to the second point that is the adoption of voltage for the super-grid lines. Whether it was necessary to think in terms of voltages higher than 220 KV even at this stage or to design the super-grid lines for ultimate operation at 380/400 KV but operate them initially at 220 KV was a matter for consideration. Various voltages were suggested, such as, 220, 270, 330 and 350, though most of the authors tend towards adopting 220 and super-imposition of 380 over the 220.

Then the next point was the agencies to bear the capital cost for the construction of super-grid transmission system and the apportionment of such costs between the participating States and the basis for such allocation. Another point for consideration was the agency for the design, construction and operation and maintenance of the super-grid systems. Whether it was necessary to establish a Central Organisation with personnel drawn from the various State Boards for this purpose. A further point for consideration was the pinciple on which the tariff should be based for the interchange of power between the participating States. Next point which had to be discussed was: Load-frequency control of interconnected systems. Another point which required consideration was that while ordering generating plant, switchgear etc. for some of the major generating stations in the country now under construction, whether it would be desirable to specify certain special features in respect of governors, controls, etc. even at this stage so that this equipment would be easily adaptible for operation when the super-grid systems are established and automatic frequency controls are incorporated.

After this reporting on the papers, the deliberation was thrown open.

Shri A. K. Bhaumik, Electrical Adviser to the Government of West Bengal stated that although it has been mentioned that complete unanimity of of opinion exists so far as the national super-grid is concerned, his idea of super-grid may be a different one. He thought that all the State Electricity Board may develop their own grids and that when all the State Grids are developed definitely, there was a case for connecting all these grids by a national grid or a super-grid.

Shri Minocha, Technical Member of the Madhya Pradesh State Electricity Board, stated that large thermal station based on low grade coal should be localised near the pit-head and the capital expenditure on the station may be borne by the States in proportion to the benefits shared by them. A joint Committee consisting of the representatives of the Electricity Boards concerned could work out the details of the financial arrangements, costs, schedule of operation and transfer of power and other incidental matters. The CW & PC under the present set-up could play an important part in co-ordinating the arrangements between the participating States. As regards the cost of energy to the beneficiary States, the obvious basis will be the cost of production including that of super-grids.

He stated that it would be advisable to plan power generation in the Third Five Year Plan with object of establishing inter-state super-grids so that large thermal power stations are put up in areas which have abundant low grade coal and which could be utilised for power generation for supply both in the State of origin and to the neighbouring States.

Dr. M. Datta, Chief Engineer, West Bengal State Electricity Board pointed out that in January, 1957, the All-India Power Engineers' Conference held at Bangalore recognised the fact that the exploitation of national resources for power generation and the scope of its utilisation should not conform to artificial barrier, or the political divisions of the country into various States and the Conference adopted a resolution suggesting planning of power development on zonal basis so as to secure the optimum utilization of resources of the regions as a whole. It is also very interesting that the present Seminar now being held at Bangalore is also considering the question of organisational procedure of establishing Super-grids. As has been pointed out by the previous speakers, the high voltage transimission has long been used for transmitting large quantities of power from the source of energy to the principal consuming centres as prevalent in the advanced countries of the world. Electrical interconnection for transferring energy across adjacent supply authorities in the U.K., European countries and the United States of America having a common land frontier has been successfully operating for many years. Power connections have been made across sea barriers also, for example, between English main-land and the Isle of Wright, between Sweden and Denmark and between Sweden and Island of

Gotland and the linking of English and French system by submarine cable is now in an advanced stage of construction. Considerable operating advantages can be achieved by such system of integration between the adjoining Supply authorities. The more important of these are as follows:

(i) The amount of spinning spare plant, banking loss and inefficient working of thermal plant can be reduced.

(ii) Reactive power flow within the adjacent can be easily controlled by easily controlled by switching in capacitor bank at the interchange point.

(iii) Power flow to and from emergency tie line between the different systems can be controlled through supervisory control.

(iv) Complete and efficient control for generation of power flow can contribute to flexibility of operation and reduce outage time.

(v) At times of peak load, all stations including old and inefficient ones in the adjacent state can be utilized and thereby additional expenditure for additions of plant is saved.

Shri Bhatia in his paper had stated that the transmission lines should be constructed for operation at 380 KV when about 300/400 MW of power has to be transmitted, but whether such high voltage line should be constructed for the present is a matter for consideration of this gathering. Of the total hydro potential (40 million KW) about 50 per cent of the water power resources is in the Brahmaputra and in the sub-Himalayan regions of Assam.

Construction of such high voltage lines for transmission of power from Assam to the load consuming centres of Calcutta at the present stage of development, of Assam is perhaps ruled out.

So far as the question of super-grid is concerned, Mr. Datta's opinion was that endeavour should be made for reinforcement of the existing grid system within limits for bulk transmission or by grouping 132 kV grid system round the future super-grid points of supply, so that eventually this 132 kV grids will form a secondary transmission system interconnected by super grids operating at 220 kV or above.

About the organisational procedure for integration, Shri Bhatia pointed out that there is no provision under the I.E. Act or the Electric Supply Act 1948 for any material benefit to the neighbouring supply authorities and some other legislation may be necessary. It is true that the Electricity (Supply) Act of 1948 has been aimed at providing for an adequate supply to meet the needs of each Statutory Board and does not specifically set out to coordinate the future generation programme on a rational basis although under the provisions of Sec. 6 of the Act, it is possible for neighbouring States to give and take back supplies and establish transmission lines for the purpose.

It will be appreciated that while the above Act of 1948 enabled considerable measure of improvement to be achieved, the general desire of the different State Boards or the supply authorities to be allowed to continue to develop power within each State or Authority's area of supply independently reacts adversely on the effective reorganisation. Co-operation between adjoining Authorities of supply is essential and for this the State Boards may have a Co-ordinating body to solve problems of mutual interest.

So far as inter-state tariff is concerned there are two distinct categories of transfer :

(1) regular supplies (2) exchanges and limited supplies. The first presupposes the existence in the supplying area of resources which, when exploited, will have more energy than is necessary to serve the local needs for some considerable time. Exports of this surplus power normally entail the construction of generating stations, special line, the cost of which must be amortized.

The second kind of transfer, on the other hand, is temporary in origin. It may be due to many factors: the difference between the variation in the hydraulic conditions in two neighbouring countries, sudden variations in the flow of rivers which might produce more power than could be absorbed in the country when they occur, the difference due to features of the thermal and hydro patterns, a hydro country supplying its thermal neighbour with a quantity of water power when it is in spate which is returned by thermal power at some other time ; co-ordination of installation maintenance programmes between the neighbouring supply authorities ; mutual aid between the two authorities, either very temporary or else based on a contract, one country having supplied to the other with capital equipment which it lacked and receiving electric power to an equivalent value in exchange ; lastly inevitable lags in the energy balance of a given country.

The South of Scotland Electricity Board, although separate from the Central Electricity Authority, has agreed as a policy that generation at steam station should be on a national economic basis as far as possible no matter where the stations are situated viz., The South of Scotland Electricity Board or Central Electricity Authority district areas.

Information on running costs of generation for various periods of the day is interchanged between Central Electricity Authority and South of Scotland Electricity Board for blocks of 20 MW and programmes are agreed between the Central Electricity Authority and South of Scotland Electricity Board's Operation engineers as indicated by their relative prices, unless otherwise, either for safety of supply or other reasons.

Such 'occasional' exchanges improve the efficiency of national network but do not result in close interdependence between the two countries.

[*Continued on page* 40

Inspection and Testing of Materials for Turbines and Generators

By L. E. BENSON AND J. JOHNSON

The use of alloys having improved properties, the special difficulties of making components of large size and the catastrophic nature of the failure of a high speed turbine or generator, should this occur, emphasize the importance of the inspection and testing procedures employed during manufacture to ensure that the required properties are in fact obtained and that the material is sound. Furthermore, as far as the main components of modern turbines and generators are concerned, it is no longer possible to include in specifications a few simple tests that alone will ensure satisfactory quality and properties.

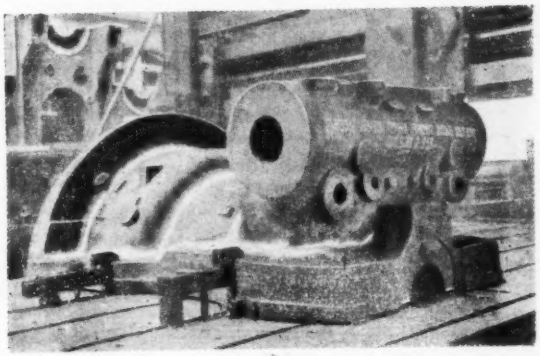


Fig. 1. The top half of a turbine cylinder and steam chest with radii ground for crack detection.

In AEI inspection practice it has been found necessary for both main forgings and castings, to take account of the manufacturing technique employed in making the original ingot or casting; and important forgings and castings are bought only from suppliers whose manufacturing procedures are approved and with whom good friendly relations are established. Check tests are chosen and test results interpreted against a background of knowledge of the metallurgical anatomy of the original ingot or casting. This implies a detailed knowledge not only of the manufacturing conditions but also of the symptoms and significance of the troubles that can arise, much as a doctor is familiar with human anatomy and the diseases from which his patients suffer; if he has known his patients from birth so much the better. To this end the Company has for many years employed its own inspectors, who are qualified metallurgists and who are responsible for following the manufacture and for supervising the testing and inspection of all main components.

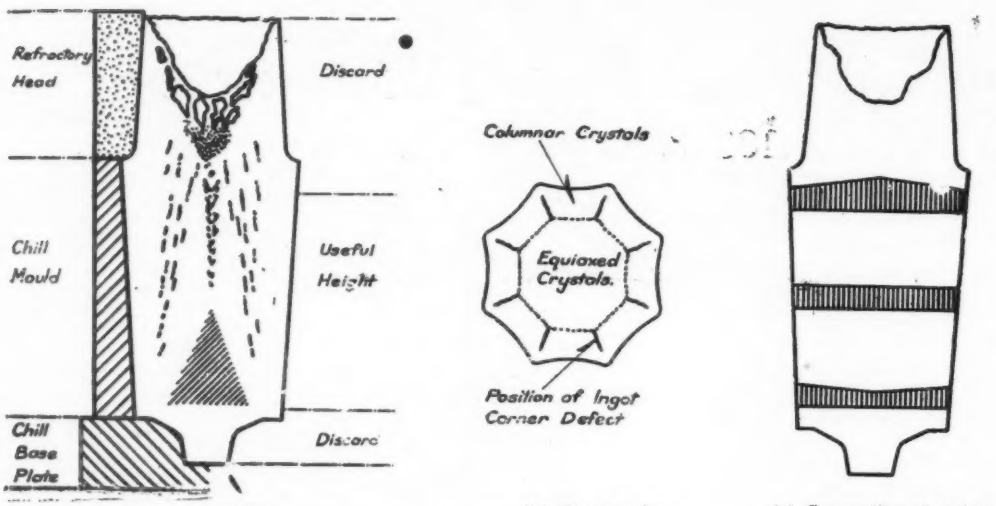
In view of the importance attached by the Company to background metallurgical knowledge it is appropriate to refer to the metallurgy of cast steel ingots and then to show how testing procedures and test results may be related to metallurgical features.

METALLURGICAL FEATURES OF INGOTS AND FORGINGS

The ingot mould and feeder head are designed so as to give the soundest possible ingot, but as steel freezes it contracts about 3 per cent. by volume and it is not unusual, even in a well-tapered ingot with a good head, for some looseness due to shrinkage to exist in the upper part of the central axis, as indicated in Fig. 2(a). Any such looseness not perfectly welded up by subsequent forging would of course remain as a weakness at the axis of a rotor forging.

However carefully the steel is melted and poured it always carries with it into the mould a certain amount of slaggy matter, mostly in the form of small particles throughout the metal. There are usually also some larger agglomerations of slaggy matter which tend to float upwards into the feeder head. These may, in part, adhere to the advancing solid wall, as the ingot freezes, to form the somewhat inclined trails of inclusions shown in an annular zone in Fig. 2(a) about midway between the centre and the outside of the ingot. Because of the characteristic inclination of these trails, like the sides of the letter A, they are known as the 'A segregates'. These segregates may show up on machining as longitudinal streaks or 'ghosts'. The A segregate zone is also important because this is where hair crack defects are most likely to form if they form at all.

The inclusions in the A segregate zone are predominantly sulphides of iron and manganese, but there is another well marked zone which tends to contain inclusions of a slaggy nature that are predominantly silicates. This is the conical shaded area in Fig. 2(a) near the base of the ingot. Defects of this type usually appear, on machining, as threads of slag on, say, a journal surface where a good deal of metal has been turned off the outside. The reason for the conical shape of this zone is



(a) Segregation of impurities (b) Cross section (c) Segregation of carbon

Fig. 2. Steel ingot features.

that these inclusions are associated with detached solid crystals which, being denser than the liquid steel in the freezing ingot, have sunk to the bottom of the ingot to build up a pile as the solidifying wall of the ingot thickens up.

The cross-section of a typical ingot is shown in Fig. 2(b). This shows, near the outside, the solid wall of columnar crystals which tend to grow at right angles to the surface as freezing proceeds and the solid wall thickens. This wall tends to contact away from the support of the mould and, if the ingot is poured too fast, the hydrostatic pressure of the contained liquid steel may cause cracking to occur at the positions indicated, in which case non-metallic matter as well as steel may be sucked into the cracks giving rise to planes of weakness at the ingot corners.

Apart from segregation of impurities and unsoundness due to shrinkage, a further complication is that the composition of an ingot is not uniform throughout. This arises from the fact that when a liquid alloy freezes, the solid crystals which form first may contain less of the solute elements than the melt, just as relatively pure ice crystals form in freezing brine. Diffusion occurs also and, in addition, as the freezing of a large ingot proceeds, isolated solid crystals may be carried round by convection currents or sink to the bottom. Variation in composition of this type concerns principally carbon, which is the element largely responsible for the hardness of a given steel (to a lesser extent it concerns some of the other elements also), and Fig. 2(c) shows very diagrammatically the way the carbon content of a large ingot varies across the section of

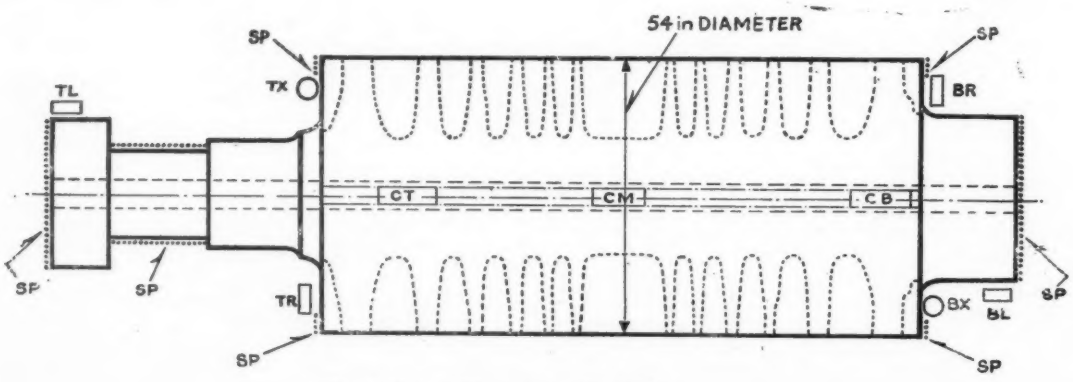


Fig. 3. Test positions on a rotor forging.
SP sulphur print
T,M,B, top, middle and the bottom of the original ingot

an ingot near the top, middle and bottom.

FORGINGS FOR TURBINE AND GENERATOR ROTORS AND TURBINE WHEELS

The most important forgings used by AEI are the monobloc rotor forgings used in generator and steam turbine constructions and the high tensile turbine wheels employed in built-up rotor construction. The following notes refer to testing and inspection methods developed by the Company and employed over many years; these methods are believed to be the most thorough employed anywhere in the world.

Table I shows the test results for a typical high tensile L.P. steam turbine rotor of 54 in. diameter. The steel was of the 3 per cent. Cr 0.5 per cent. Mo type and test pieces were machined from positions indicated in Fig. 3. Having regard to the size of this forging such figures are regarded as representative for the best practice anywhere today.

Tests at the axis of a rotor forging are not a specification requirement and the tests reported here were taken from the trepanned core for our own information in line with our regular practice.

The variation in properties shown here is due to variation in composition of the type mentioned above, the figures being normal. Indeed, more pronounced variation can occur, an example being give in Table II. The position of the test pieces is again as indicated in Fig. 3, the letters T, M and B standing for top, middle and bottom of the forging relative to the ingot. The variation in tensile strength corresponds with the variation in carbon content as indicated in Fig. 2(c).

The trepanned core is also examined for microstructure as an additional check that the heat treatment has been effective throughout the body and as a check against unsoundness of a type that might not be removed by the bore. This has been normal AEI procedure on all important rotors made at the main factory at Trafford Park for more than thirty years and, in view of the experience gained, the employment of unbored forgings, relying solely on the ultrasonic test for disclosing axial unsoundness, as is now the fashion in Germany and elsewhere, would not be countenanced.

The bore is tested magnetically for discontinuities, such as cracks or closed up shrinkage cavities, magnetization of the bore surface being effected by passing current through a conductor threaded through the bore. About 1500 ampere-turns is normally satisfactory and to avoid the use of heavy currents a multicore cable with 45 turns, which can be connected to a 240-250 d.c. supply, is used. The bore is subsequently washed with a suspension of magnetic powder in kerosene and examined by means of a periscope.

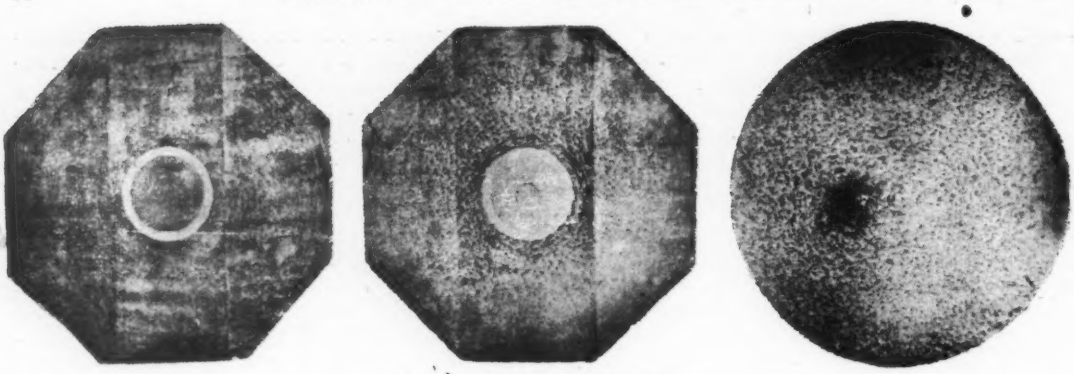
The positions from which sulphur prints are

TABLE I—TEST RESULTS FROM 54-INCH DIAMETER LOW PRESSURE STEAM TURBINE ROTOR

Position	*0.2% Proof Stress (tons/in.²)*	*Ultimate tensile strength (tons/in.²)*	*Elongation %*	*Reduction in area %*	*Bend degrees*
Ends TL	34.6	46.6		67.8	180
Ends BL	33.2	45.3	26.1	67.0	180
Body TX	34.1	45.9	24.2	53.9	180
Body BX	32.9	45.0	24.2	57.3	180
Body TR	33.8	46.1	22.2	55.1	
Body BR	33.4	45.6	23.0	62.6	
Core CT	35.3	46.9	25.0	61.5	
Core CM	36.1	48.2	19.3	45.6	
Core CB	33.3	42.8	26.9	70.0	

TABLE II—TEST RESULTS FROM 34-INCH DIAMETER CARBON STEEL ROTOR SHOWING VARIATION DUE TO CARBON SEGREGATION

Position	*Yield point (tons/in.²)*	*Ultimate tensile strength (tons/in.²)*	*Elongation %*	*Reduction in area %*
Ends TL	25.5	45.6	20	39.2
Ends BL	24.0	42.5	23	41.9
Body TX	26.0	45.8	18	24.6
Body TR	25.0	45.0	17	30.6
Core CT	25.5	47.5	18	36.4
Core CM	26.0	47.8	8	10.0
Core CB	21.5	39.6	28	41.9



(a) Transverse section of a large forged ingot—bottom end

Fig. 4. Typical sulphur prints.
(b) Transverse section of a large forged ingot—top end

(c) Transverse section of a defective rotor forging—top end showing pronounced segregation

taken to disclose segregation of sulphide inclusions is shown on Fig. 3. The freezing of a big ingot takes several hours during which the sulphide inclusions tend to float upwards through the liquid steel and a generous discard, including the head and top portion of the ingot, is taken at the forge to remove dirty metal. As a check that an adequate discard has been taken so that the remaining forging is satisfactory, sulphur prints are taken from both shaft ends of each rotor. Even in a satisfactory forging there is always some difference between the top and bottom ends. Fig. 4 illustrates this. The sulphur prints shown at a and b are normal. The print shown at c contains objectionably pronounced segregation towards the centre (note that the shaft end was slightly off centre relative to the original ingot).

The risk of ingot corner weakness was referred to earlier and to check for this sulphur prints are taken from the periphery of the rotor body at each end, as indicated in Fig. 3. A print disclosing a bad defect of this type is shown in Fig. 5. The extend of the defect radially is about two inches. As the plane of weakness is due to particles of slag each of which is probably of microscopic dimensions, the defect might not be noticeable on a machined surface. The effect of pronounced ingot corner segregation on mechanical properties is indicated in Table III.

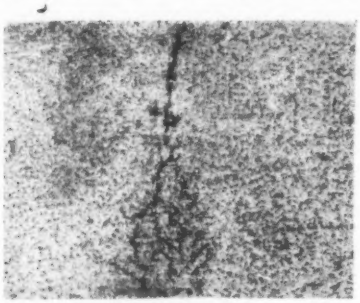


Fig. 5. A typical sulphur print from the edge of a rotor body showing ingot corner segregation.

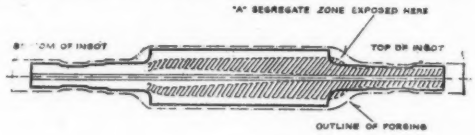


Fig. 6. The position of the 'A' segregate in a rotor forging.

Sulphur prints are also taken at bearing journal location at the rough machined stage, and visual inspection is made of all rough-machined surfaces including the gaps between wheels on turbine rotors.

So far no reference has been made to the risk

TABLE III—EFFECT OF INGOT CORNER SEGREGATION ON MECHANICAL PROPERTIES

	Tensile Test				*Blend Test*	*Izod*
	Ultimate tensile strength (tons/in.²)	*Yield point (tons/in.²)*	*Elongation %*	*Reduction in area %*	*Degrees*	*ft. lb.*
Sound steel	41.2	33.1	35	57	180	51
Across I.C.	40.4	32.8	10	4	15	18
Across I.C.	32.2	32.9	0	3		

of hair-cracks, except to note that they are most prone to occur at positions corresponding to the A segregate zone in the original ingot. Hair-cracks are normally too fine to be found by visual examination of a machined surface and their association with the A segregate means that they might not occur at the surface anyhow. The disposition of the A segregate zone in a typical rotor is such as shown in Fig. 6. It would appear from this that magnetic examination of the bore at the top shaft-end might be effective, but, because of the reduced cross-section of the shaft-end, hair-cracks are less likely to form there than in the body. From about 1928 therefore until the ultrasonic method of testing for internal defects became available and until faith in it had been established, the procedure adopted was to have the rotor bodies forged longer than necessary at the top end, and then machined back so as to be certain of cutting right into the A segregate zone. The fillet between shaft and body so formed was then tested magnetically. This procedure led to the rejection of a number of forgings, investigation of which confirmed the existence of hair-cracks disposed within the body as expected. Just how bad these can be is illustrated by Fig. 7. This shows a transverse section of a rotor rejected in 1928 and subsequently cut in two for investigation, the hair-cracks being made visible by a magnetic test of the machined section.

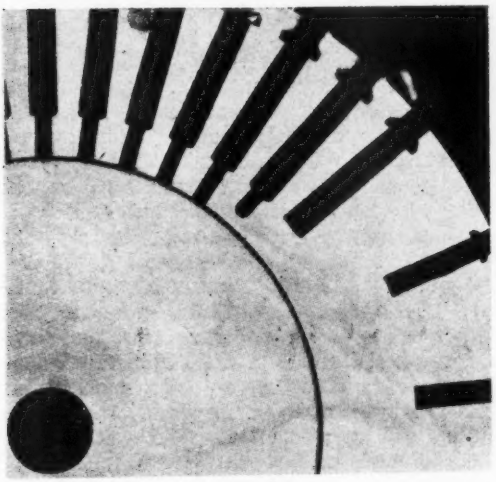


Fig. 7. Hair-cracks disclosed on a section of a rotor by a magnetic test.

Within more recent years experience with the ultrasonic method of testing led to its general adoption as a satisfactory means of checking for hair-cracks and certain other internal defects in turbine and generator rotors, turbine wheels and other components. Routine ultrasonic tests are carrid out at

Fig. 8. An ultrasonic test in progress on a turbine wheel.

the suppliers' works and the final check is repeated in the company's works. Fig. 8 shows such a test being applied to finish-turned turbine wheels.

ULTRASONIC TESTING

The ultrasonic method of testing is now a very valuable non-destructive technique for assessing the soundness not only of foreigns but also of plate materials, welds and other structural components. Modern equipment can be made extremely sensitive to discontinuities of small area in the test material, and the ultimate limitation of its use arises when the defect echoes are too small to stand out against the background picture due to grain size effects or the inherent heterogeneity of steels and other alloys.

In its application to forgings, the wide range of frequencies and the multiplicity of probes now available provide the flexibility of technique necessary

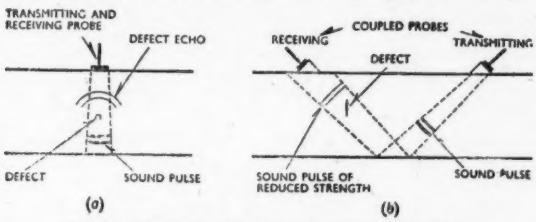


Fig. 9. Examples of ultrasonic testing methods.

to ensure detection of those flaws whose orientation in relation to the external geometry of the forging may introduce some difficulty. As an example Fig. 9 shows the principle of two methods of testing which have been adopted for the final approval of turbine discs. The conventional method of testing is eminently suited to the detection of most of the flaws which could arise in the ingot or during forging and which, due to the process of 'upsetting' will lie predominantly in planes parallel to the hub faces. This is illustrated in Fig. 9(a). Fig. 9(b) shows a supple-

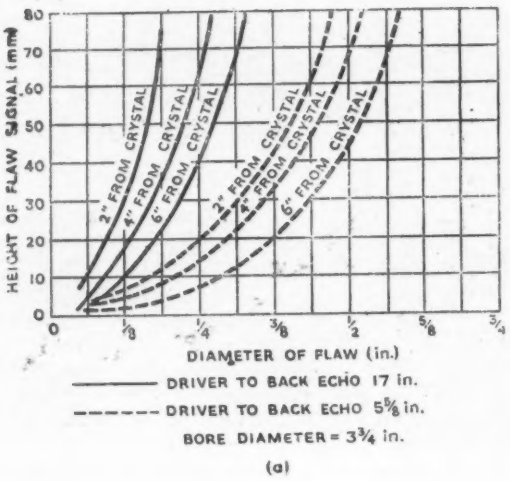
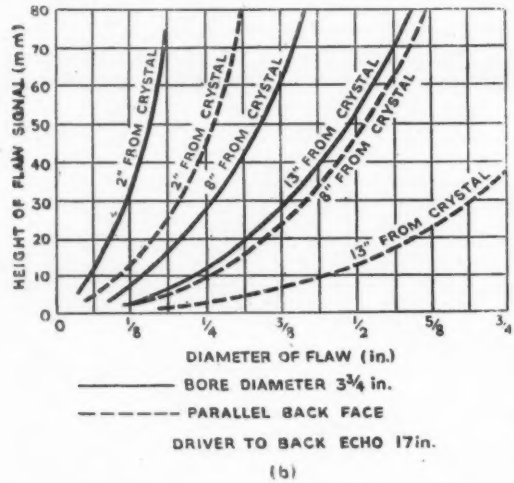


Fig. 10. Specimen calibration charts for ultrasonic testing. These relate flaw echo size to flaw diameter (for a fixed bottom echo amplitude) over a range of distances of the flaw from the test surface.

(a) shows in addition the displacement of the curves resulting from a change in the radial dimension

(b) shows in addition the displacement of the curves resulting from a change in bore curvature.



mentary test designed to ensure that thermal cracks occurring in radial planes normal to the hub face are also detected, the application of the technique being illustrated in Fig 8.

Whilst the method exhibits extreme sensitivity, its application as a diagonstic tool (necessary in trying to assess the significance of the indications found) demands the accumulation of a great deal of background data and experience. Interpretation of the essentially simple information derived from

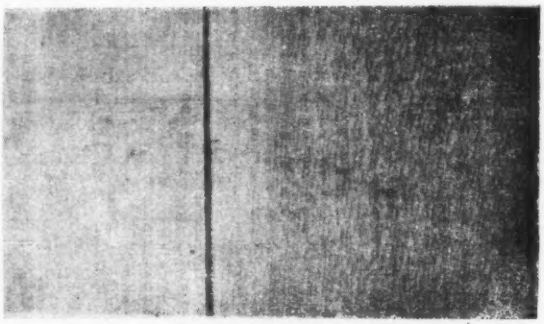


Fig. 11. Stress corrosion cracking disclosed by machining the surface of a ring which has been in service.

the test must take into account many factors which influence the relationship between the ratio of flaw indication to back echo, and the size of the flaw. It is quite impossible to define in a specification a simple criterion for acceptance or rejection of a forging in terms of defect echo amplitudes, even for a component whose geometry is as simple as that of a rotor forging.

Considering the simple case of an ungashed but bored rotor body, and testing it from the periphery with a normal probe so that a bottom echo is obtained from the bore, the amplitude of the echo obtained from a flaw will be influenced by all of the following factors :—1. The size, character and orientation of the defect. 2. The depth of the defect below the test surface. 3. The total radial distance between surface and bore. 4. The curvature and roughness of the bore surface. 5. The curvature and roughness of the peripheral surface. 6. The efficiency of the coupling between the probe and the test surface. 7. The ultrasonic frequency used. 8. The attenuation factor for the steel which in turn depends on grain size as well as composition.

By standardizing amplitude of the bottom echo, the effects of 5 and 6 can be corrected. The choice of frequency may be dictated by the structural condition of the forging, but in bored fully-treated forgings it is usually a compromise between maximum sensitivity, signal attenuation, and the need to ensure a sufficiently wide beam angle to detect radial defects in the vicinity of the bore. Frequencies from 1 to 2.5 Mc/s and crystal sizes from 1.5 to 2.5 cm are commonly employed.

The character and orientation of defects revealed ultrasonically can often be deduced from a knowledge of the history of the forging and the results of other inspection techniques, but the interpretation of ultrasonic indications sometimes requires extensive supplementary investigation including exploration with angle probes to determine the orientation of the discontinuities.

Factors 2, 3 and 4 may be covered by the use of

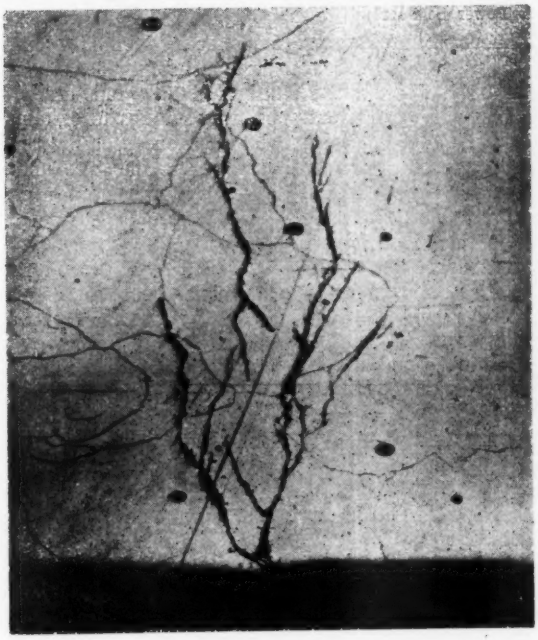


Fig. 12. Microsection normal to the surface of a nonmagnetic steel ring showing stress corrosion cracking 0.030 in. deep. The faint markings are the normal crystal boundaries.

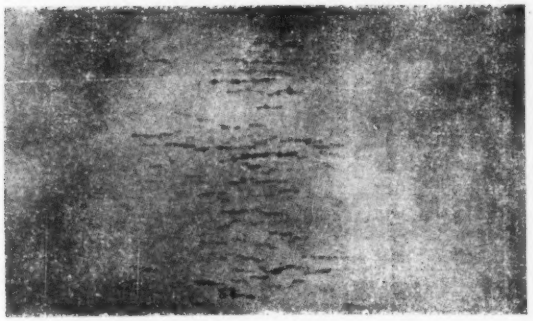


Fig. 13. Stress corrosion cracking (fairly severe) revealed by the dye-penetrant method on a ring that has been in service. Some, but not all, of the cracks were visible without the dye-penetrant test, and all were removed by machining to a depth of 0.18 in.

calibration curves or of tabulated data obtained from standard test blocks used in conjunction with an attenuator. Fig. 10 shows the effect on the defect echo size produced by these three factors. These curves were obtained on test blocks using the flat bottom of a drilled hole to simulate a planar defect. They thus represent the conditions obtaining for defects of the most favourable orientation, and their use will give the minimum effective diameter of any real flaw.

Ultrasonic inspection of rotor forgings can be usefully applied at several stages in manufacture. Whilst examination in the rough-forged or even in the bloomed condition can segregate potentially good forgings from those whose condition even at this stage indicates their unsuitability for service, the final acceptance inspection must be undertaken after all heat treatment is complete and with the forging in the finish bored condition.

The curves illustrated in Fig. 10 cover only a fraction of the whole field, but they serve to demonstrate the impracticability of specifying acceptance and rejection criteria based simply on ultrasonic indications. The acceptance of any forging depends on the interpretation of the ultrasonic indications, against a background of fundamental data and the results of other metallurgical tests, considered in relation to service conditions. Experience suggests that the demands made by AEI on forging suppliers, in regard to soundness, are of the highest stringency.

NON-MAGNETIC STEEL COIL BINDING RINGS

The non-magnetic steel coil retaining rings, or end-bells, which are fitted to the ends of generator rotors to support the projecting ends of the field coils are a special class of forging in that the mechanical properties are obtained by a 'warm working' process and the material, being austenitic, is susceptible to stress corrosion cracking. Over a thousand ring of this type have been used on generators made at Trafford Park alone in the last twenty-five years, and not one of these has failed. Nevertheless the advent of silicone base enamels has enabled an improved technique to be adopted. The whole surface of each ring is now treated with a baked on coating of silicone base enamel which protects it from corrosion and thus from the risk of corrosion cracking. The finish imparted to the rings on finish-machining has also been standardized.

The inspection of unprotected rings for stress corrosion cracks presents a problem, because magnetic methods of crack detection cannot be applied. A very sensitive test is to take a light machine cut over the surface, when simple visual examination will reveal the presence of even superficial cracks.

This is satisfactory for new rings which can be inspected and enamelled immediately after finish-machining and it is the most searching method of examining rings that have been in service, if it can be applied. The next best method is to clean the surface as carefully as possible so as to expose a continuous surface of bare metal and then apply a dye-penetrant test.

The characteristic appearance of stress corrosion cracking is shown on Figs. 11, 12 and 13.

(To be continued)

[*Continued from page* 32

Seventh Irrigation & Power Seminar

Moreover, they do not need the construction of a special network but merely drawing of certain lines at the frontiers as the intensity of exchanges increase which can be shared between the two participating supply authorities. Such integration of generating plant and its operation as a common pool will give worthwhile economic results for both the Supply Authorities and for the country as a whole. Hence for the formulation of Tariff, the principle can be laid down by the proposed Central Legislature suggested by Mr. Agarwal and rates are to be worked out by the participating states and have to be agreed upon in mutual interest for generation of power on a national economic basis. No doubt rates have to be based on the running cost of most efficient thermal stations for regular supplies but the case of spill power at a much lower rate is called for. The generating station should be established where it is most economical and power should be generated not on basis of any state or other areas but purely on national consideration.

There were many other persons in this gathering such as, Mr. Agarwal, I.C.S., Shri Minocha (Technical Member, M.P.) Mr. V. V. Dravid (Minister of M.P.), Mr. P. R. Sundaram, Mr. Tata Rao, Shri K. M. Chinappa, Mr. Kulkarni, Mr. Patil, Mr. Pathak, Mr. Pappu, Mr. S. V. Deshmukh and a few others, who took part in the discussion. A Sub-Committee was formed to go into the merits of the case and the report of the Sub-Committee is given below :

"The ten papers presented at the 7th Irrigation and Power Seminar and the discussions which were on the 11th September 1960 on this subject have shown a unanimous measure of agreement on the need for establishing Super-Grids on a Zonal basis, keeping in mind their gradual evolution into an All-India Grid in due course.

"The various advantages of a Zonal Super-Grid such as beneficial exchange of power between the States served by the Grid, substantial reduction in stand-by capacities, operation of most efficient stations at the highest load factor, optimum exploitation of Hydro sites, establishment of thermal stations at pit heads (utilising low grade fuel), assignment of different generating stations to certain sectors of the load curve of the Zone as a whole, thus securing generation of power at the minimum cost practicable and its supply wherever needed in the zone for the benefit of the region as a whole, were high-lighted. While planning the Super-grids care should be taken to see that large generating stations are established at the most economical sites in the region as a whole.

"As regards the agency for planning, designs, construction, operation and maintenance of Zonal grids, various views were expressed, but the consensus was that Super-grids should be planned, designed, constructed and operated by a Central Agency for each Zone. It was further suggested that the possibility of establishment of a Central generating agency who shall be responsible for generation and transmission of power to Super-grid receiving stations be also considered. The necessity for a master plan was keenly felt. It was agreed that, as an initial step, a Cell should be established in the Central Water and Power Commission to take up the question of planning Zonal Super-Grids in association with the State Electricity Boards, and Public Electric Supply undertakings and Corporations, and it should be adequately staffed to accomplish the objectives as early as possible. The Cell may also study the various aspects with regards to organisation, financing, construction, operation and maintenance of super grids and submit proposals for consideration of the subject at the next Seminar.

"With regard to the voltages to be adopted, the Cell to be established should study the problem of each zone on the Net work Analyser at Bangalore and recommend adoption of appropriate voltages after taking into consideration the technical requirements and the economics of the proposition."

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Editorial

Thoughts on the Indus Treaty

The Indus Waters Treaty has at last been signed by India and Pakistan. The protracted talks extending to over a decade has now come to a close and let us hope that this major and burning issue creating distrust between the two countries will not recur again.

It reminds us that Mr. David Lilienthal, formerly President of the TVA, was the first to suggest an agreed basis for the development of the Indus Basin. However, it may be noted that he had suggested an altogether different approach for the development of the Indus Waters. His idea was that the total run-off of the rivers in the basin should be planned as a unified entity for optimum development, so that both the countries may be benefited as much as possible. There was no idea of a strict division of the rivers. But as the World Bank began to negotiate with the two countries, it soon became evident that such a basis of development would not be acceptable to them. What constituted the exact reasons for this were not made clear. One can only surmise. Possibly because of the lack of trust between the two countries, having been recently partitioned in an atmosphere of anger and hate, they thought it will not be wise to accept an arrangement which would keep both of them dependent on one another. The World Bank had, therefore, no other alternative but to consider the idea of dividing the rivers between the two countries. This has been the basis of the present Treaty. Even then the negotiations took such a long time.

From the press reports it appears that a few weeks before signing the Treaty some hitches had developed and, as a result of the personal intervention of the Prime Minister of India, the agreement became possible. Again, what the issues were which came in the way at the very last moment are not known to the public. Possibly the official representatives of India thought that the terms were too generous to Pakistan to the detriment of India, especially with regard to the financial contribution that India is to make. But the Indian Prime Minister was not assessing the benefits from the Treaty only in economic terms. He was viewing it as a stepping-stone to a further stage of friendly relations between the two countries. Only in this background can we explain the admittedly generous concessions that India made at the very last moment to Pakistan before signing the Treaty.

Viewed from this angle, subsequent reactions in Pakistan towards India on problems other than the Indus Waters indicate that there was not sufficient justification for the considerations which inspired our Prime Minister. We are definitely of the opinion that the future of this sub-continent depends upon the close collaboration between these two countries. The only question that arises, therefore, is how to the close collaboration between these two countries. whose relationship has been bedevilled from the very start. It seems to us that if compromises have to be made and a spirit of give and take is to inform all the problems between these two countries, the better course would be to take all the problems together and come to a package settlement. Only then compromises and large-heartedness shown by one country towards another will have meaning and significance.

In this case of the Indus Treaty, the above approach has obviously not been made. The problem has been dealt with in isolation and a solution has been arrived at. But has this improved the relationship between the two countries? We very much doubt. Concessions have been made on the part of India—substantial concessions indeed, but to what purpose?

From the very beginning we had clearly stated our position with regard to the Indus Waters. We completely agreed with Mr. Lilienthal and we thought that it was not desirable for the waters to be divided territorially. Regional development, if it has to secure optimum results, must be based on the consideration of the region as a unity. Political boundaries, whether national or provincial are not to be considered sacrosanct. This approach should have been seriously attempted in the Indus Basin. For what was at stake was not only the future of the Indus but also of the river system in the eastern region of India and Pakistan. Howsoever the two states may try to live in isolation of each other, they can hardly afford to quarrel with history as well as geography. Interdependence is part of their fate. It would be much better, therefore, for both to face the reality squarely.

We are not suggesting by this that the Treaty is not proper. Far from it. We fervently hope that the Treaty will be worked in the right spirit, for this itself will create the right attitude to deal with other problems. All that we wish to state is that the two countries could have, and should have, done better and that too, much earlier. And from this an important lesson needs to be learnt. This lesson can prove most useful when the two countries will deal with the development of the rivers in the Eastern region which is much more complicated and which has now begun receiving attention.

The problem in South East Asia is one of sound and rapid development of natural resources, of which water is one of the most important. Most of

the countries in this region are small and the major river systems cut across the national boundaries of more than one. India and Pakistan are two major countries in the area and if they could give a proper lead in regional development covering international rivers on a unified basis, they would have contributed in a substantial way towards regional development in other parts of the area as well. It is in this setting that we look at the Indus Treaty. It is good as far as it goes, but provides no leadership.

Our Contributors

Mr. V. P. Appadurai joined Madras Electricity Department during 1932. He rose to the position of Superintending Engineer of the Technical Branch in 1948 and became Chief Engineer of the Madras Electricity Department in 1954. After the formation of the State Electricity Board in 1957, he is now the Chief Engineer and Technical Member of the Board.

During 1952 he visited U.S.A., Canada, U.K., and the Continent under the Colombo-plan Fellowship Award.

During 1956 he went to Canada as a Member of the Government of India, Delegation to finalise the terms of Colombo Plan Aid for the Kundah Hydro Electric Scheme. He again went to Canada during 1955 for finalising the orders for plant and machinery required for the Kundah Project, and to Germany during 1958 to expedite the despatch of the generating machinery required for the Periyar Scheme.

Mr. B. K. Banerjee graduated from Bengal Engineering College, Sibpore, and obtained first class. After an initial period with the English Electric Co. Ltd., and Andrew Yule & Co. Ltd., joined Electricity Development Directorate, Government of West Bengal in 1950. Now Divisional Engineer in charge of Commercial Division, West Bengal State Electricity Board. Toured United Kingdom and the Continent under the Colombo Plan in 1957-58 for about six months and had specialised training in the East Midlands Electricity Board, U.K. in tariff, load survey, load development and other commercial matters.

Mr. R. D. Dhir I.S.E. after qualifying from the Thomson Engineering College, Roorke, in the year 1929 joined the Sind P W.D. as ISE student and rose to the rank of Chief Engineer in 1956. Has travelled extensively in Middle East and Europe. Member of various consultative Commissions both Indian and International. Author of various technical books and papers. Specialist on Irrigation, Hydrology and Flood Control. At present Chief Engineer, Floods, in the Central Water and Power Commission.

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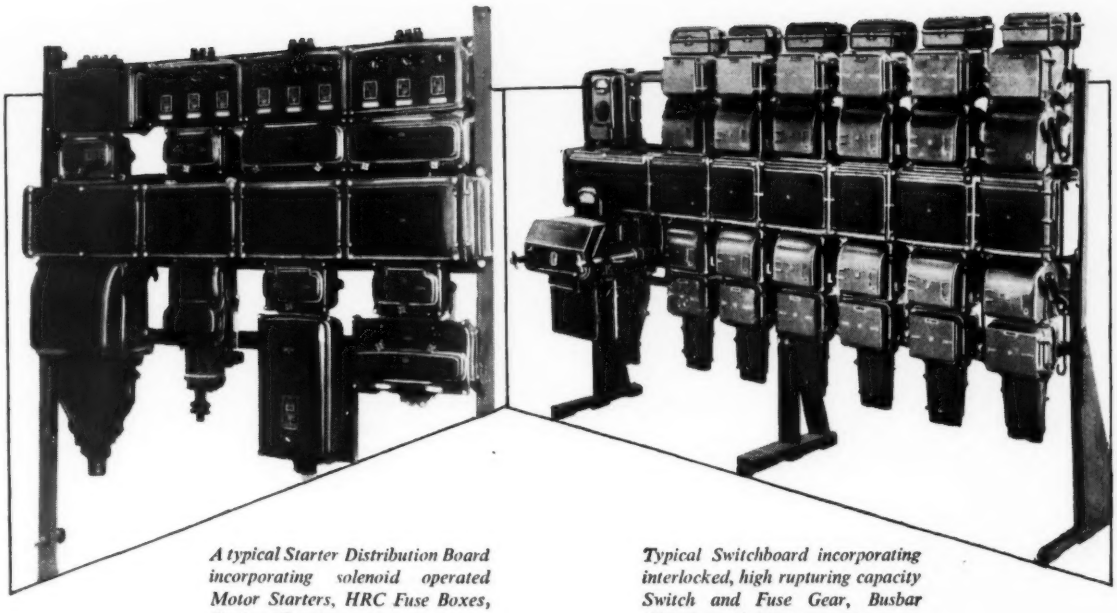

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